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U.S. Dept of Army

TECHNICAL MANUAL

AVIATION ENGINEERS

December 31, 1942

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WAR DEPARTMENT,
WASHINGTON, May 13, [illegible]3.

TM 5–255, December 31, 1942, is changed as follows:

Figure 63 is rescinded and the following substituted therefor:

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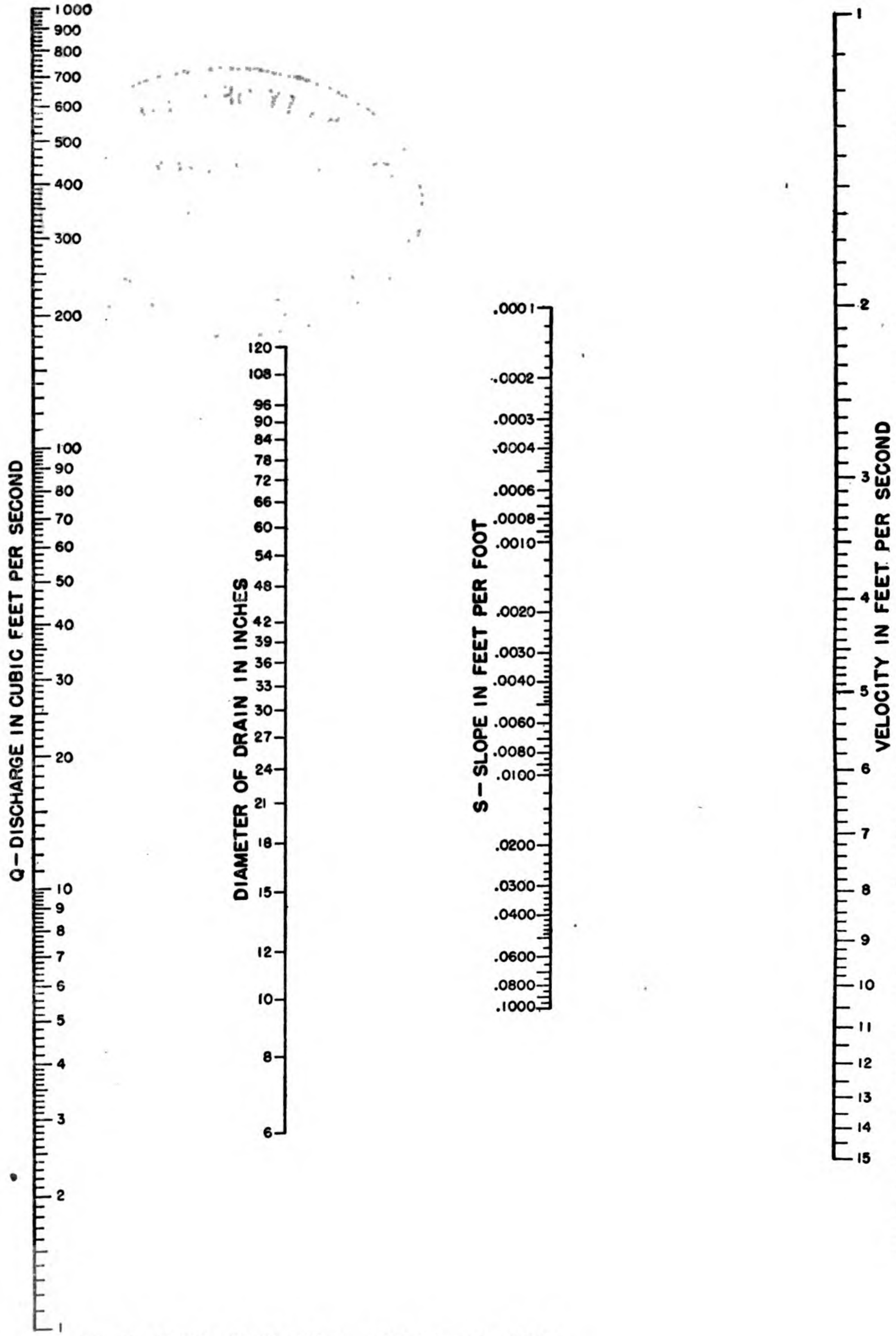

FIGURE 63.—Graphical solution of $Q=100\,Ar^{2/3}\,S^{1/2}$ for circular pipes (based on Manning's formula for $n=0.015$).

[A. G. 062.11 (4–22–43).] (C 1, May 13, 1943.)

BY ORDER OF THE SECRETARY OF WAR:

G. C. MARSHALL,
Chief of Staff.

OFFICIAL:

J. A. ULIO,
Major General,
The Adjutant General.

U. S. GOVERNMENT PRINTING OFFICE: 1943

TENTATIVE
TECHNICAL MANUAL
No. 5-255

WAR DEPARTMENT,
WASHINGTON, December 31, 1942.

AVIATION ENGINEERS

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CHAPTER 1

MISSION

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General	1
Purpose and scope	2
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1. General.—Engineer aviation units are a component of the Corps of Engineers organized to meet the needs of the Army Air Forces for engineer work in theaters of operation. This work consists primarily of constructing, maintaining, camouflaging, and defending field airdromes. However, tasks of construction vary from permanent air bases to runways hurriedly cleared for advanced landing fields.

2. Purpose and scope.—*a.* This manual covers both tactical and technical phases of the training and operations of aviation engineers,

FIGURE 1.—Keep 'em flying.

with special reference to their employment in theaters of operation. It does not cover all the problems which aviation engineers will encounter on battle fronts around the world. *In every situation general engineering principles must be applied with sound judgment.* This manual is a guide to those principles and to their application.

b. The subject matter of this manual falls naturally into four parts. The first part covers general background—mission, organization, equipment, and training. The second part (chs. 5 to 13 incl.) deals with operations in constructing, maintaining, and defending field airdromes, including methods of using the construction equipment issued to aviation engineers. Camouflage, which must be considered in all phases of airdrome development, is then covered. Following the camouflage chapter there is a chapter on airborne aviation engineers which covers their mission, organization, equipment, and training. The appendixes furnish detailed technical and reference data. Appendix III, on soils, is particularly important to an understanding of many design and construction problems covered in other chapters.

c. No attempt is made to cover pioneer construction methods and the use of hand tools since they are covered in TM 5-225 and FM 5-10. The discussion of camouflage is supplementary to that contained in TM 5-266 and FM 5-20. Data concerning materials for camouflage purposes are found in TM 5-269.

3. Duties of engineer aviation units in airdrome construction.—*a. Landing fields.*—Construction, maintenance, and repair of runways, taxiways, and hard standings. Includes placing of steel runways.

b. Ground installations.—(1) Construction and maintenance of facilities for refueling and arming aircraft; for storage of gasoline supplies, ordnance supplies, and air force supplies; for housing personnel and equipment; and for shop repair and maintenance of air force equipment.

(2) Construction, maintenance, and operation of utilities for water supply, light, heat, and power.

c. Communications.—(1) Construction, maintenance, and repair of service roads within the airdrome and of supply roads adjacent to the airdrome.

(2) Construction, maintenance, and repair of railroad facilities within the airdrome.

d. Camouflage.—Dispersion and concealment of ground installations, concealment of airplanes on ground, and construction of dummy targets. Also camouflage instruction, technical advice, supply of camouflage materials, and assistance to other air force personnel.

e. Airdrome defense.—(1) Local security of own troops.

(2) Assistance in local airdrome defense against air or ground attack.

(3) Construction of weapons emplacements.

(4) Provision of protective structures for personnel and facilities.

(5) Obstacle construction, including laying antitank mines.

(6) Preparation of demolitions to prevent enemy seizure of airdrome facilities.

4. Other duties of engineer aviation units.—Other duties of engineer aviation units are—

a. Repair and rehabilitation of captured airdromes, including removal of booby traps and land mines.

b. Mapping and map reproduction, including assistance in field preparation and reproduction of aeronautical charts such as navigation charts, approach charts, and target maps.

c. Establishment and operation of engineer supply.

5. Definitions.—*Airfield* is the general term applied to any area of land used for the landing and take-off of aircraft. An airfield with military facilities for shelter, supply, and repair of aircraft is called an *airdrome.* The following terms are used in describing airdromes:

a. Air base.—An area command for supply and administrative purposes consisting of a main parent airdrome, or base airdrome, and one or more smaller airdromes spread out at some distance from the parent field. These smaller airdromes may be called *auxiliary airdromes* or *satellite fields* because they are in the area of the air base and depend upon the parent field for complete repair and supply facilities.

b. Dispersed airdrome.—An airdrome at which runways and all facilities for aircraft have been spread out (dispersed) to make them less vulnerable as targets.

c. Field airdrome.—A dispersed airdrome, generally in the theater of operations, built for wartime use only. Construction is the minimum consistent with military necessity. The base airdrome or the satellite fields mentioned in *a* above may be field airdromes. This manual is concerned mainly with field airdromes.

d. Alternate airdrome.—An airdrome available for the use of air force units in place of the one to which they are assigned.

e. Staging field.—An airdrome available for temporary occupancy of military aircraft during movements from one airdrome to another.

f. Advanced landing field.—An area in the combat zone used for the landing and take-off of aircraft. Where runways are used, normally there is only one, and that one of temporary construction. Only minimum facilities, if any, are available for servicing. At most they consist of drums of gas, cases of ammunition, and light bombs stacked under available natural cover.

g. Landing strip or flight strip.—A straight section of existing sur faced highway, or a strip adjacent to a highway, suitable for quick conversion into a runway. It may require highway traffic control and a bypass road.

h. Cleared zone.—A cleared and graded area for the landing and take-off of aircraft, including runway and shoulders.

i. Runway.—The portion of the cleared zone, usually along the center line, which is surfaced for all-weather landing and take-off of aircraft.

j. Approach zone.—An obstruction-free trapezoidal area at each end of the cleared zone.

k. Angle of glide.—The slope of a line extending upward and outward from the end of the cleared zone, above which no obstruction may extend within the area of the approach zone. Slopes vary from 50 to 1 to 20 to 1.

l. Obstruction.—Any object which presents a hazard to flying on an airway near an airdrome or which interferes with the safe landing and take-off of aircraft.

m. Taxiway.—Cleared, graded, and surfaced ways over which airplanes may taxi or be towed. Taxiways connect parking areas and runways providing traffic circulation.

n. Parking area.—An area in which a number of aircraft are parked. A surfaced parking area for a single airplane is called a *hard standing.* A surfaced area known as an *apron* is used for parking more than one airplane.

CHAPTER 2

ORGANIZATION AND DUTIES

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Engineer aviation company 14
Engineer aviation regiment 15
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6. General.—*a.* Engineer aviation units are organized along the same general lines as combat and general service engineer units.

b. To understand the organization of the aviation engineers, it is necessary to know the organization of the air forces. Figure 2 shows the organization of a typical air force with particular reference to the aviation engineers.

c. It must be understood that organization is subject to change. Different theaters of operations may require special organizational features in each case. This chapter is a general guide only and is based on Tables of Organization as of October, 1942.

7. Units.—*a.* Engineer section, headquarters, air force (T/O 5-800-1).

b. Engineer air force headquarters company (T/O 5-800-2).

c. Engineer aviation topographic company (T/O 5-447).

d. Engineer section, headquarters, air service command (T/O 1-400-1S).

e. Engineer aviation regiment (T/O 5-411).

f. Engineer aviation battalion (T/O 5-415).

g. Engineer aviation camouflage battalion (T/O 5-95).

h. Engineer aviation company (T/O 5-417).

i. Airborne engineer aviation battalion.

8. Staff functions.—*a.* Engineer staff functions in an air force are conducted generally in two separate engineer sections. These are the engineer section of the air force headquarters and the engineer

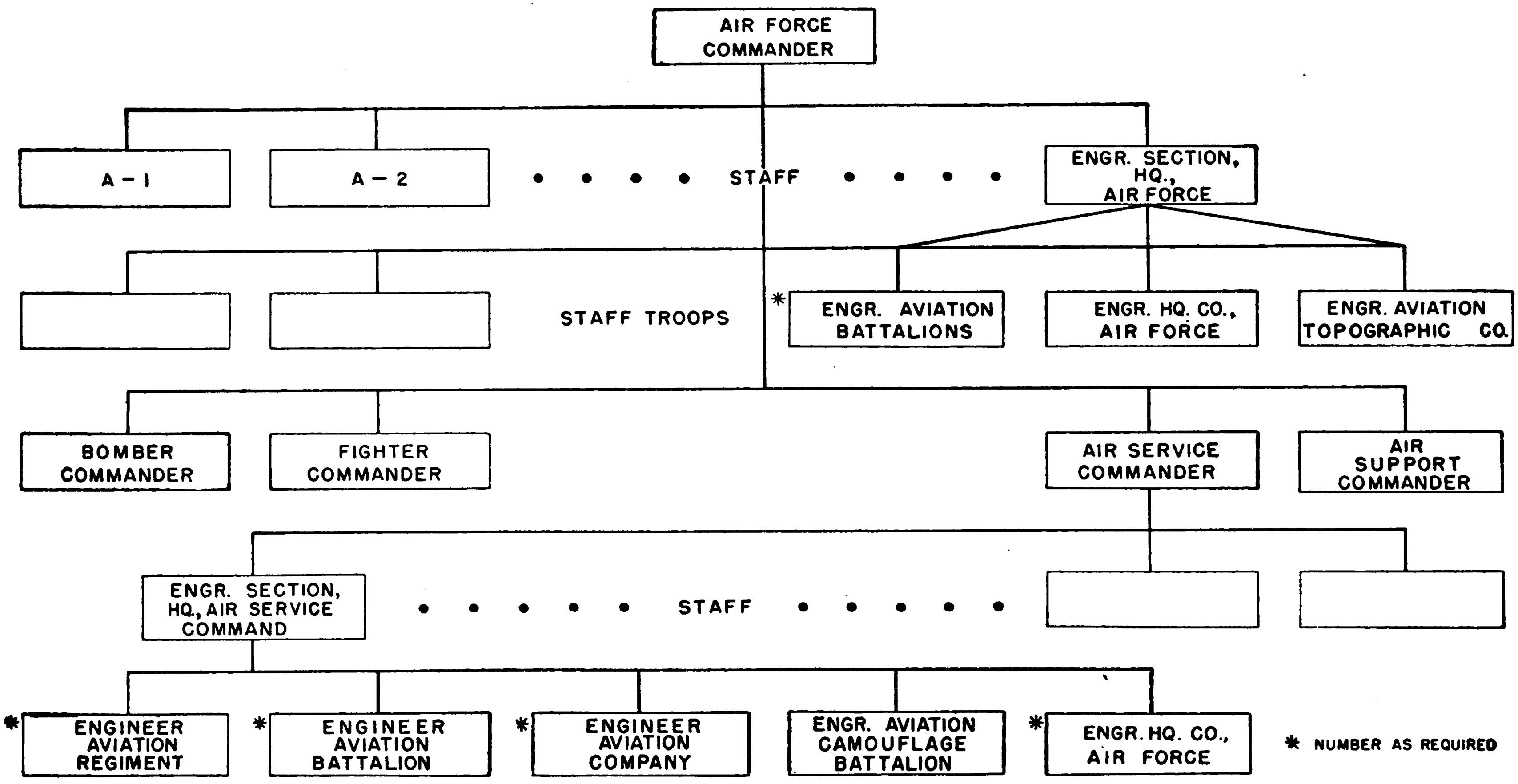
AIR FORCE COMMANDER
A – 1
A – 2
STAFF
ENGR. SECTION, HQ., AIR FORCE
STAFF TROOPS
* ENGR. AVIATION BATTALIONS
ENGR. HQ. CO., AIR FORCE
ENGR. AVIATION TOPOGRAPHIC CO.
BOMBER COMMANDER
FIGHTER COMMANDER
AIR SERVICE COMMANDER
AIR SUPPORT COMMANDER
ENGR. SECTION, HQ., AIR SERVICE COMMAND
STAFF
* ENGINEER AVIATION REGIMENT
* ENGINEER AVIATION BATTALION
* ENGINEER AVIATION COMPANY
ENGR. AVIATION CAMOUFLAGE BATTALION
* ENGR. HQ. CO., AIR FORCE
* NUMBER AS REQUIRED

FIGURE 2.—Aviation engineer organization in a typical air force.

section of the air service command headquarters. There may be additional engineer staffs with fighter, bomber, and air support commands when these commands operate independently. The duties assigned respectively to the air force engineer and to the air service command engineer may be modified in each case by the air force commander. The two engineer sections may sometimes be combined in one. The division of duties given in paragraphs 9 and 10 is a guide.

b. In general, operations of aviation engineers with an air force which are concerned with the selection and construction of new airdromes come under the direct supervision of the air force engineer. This is especially the case in a mobile situation, as in an advance into hostile territory. On the other hand, all engineer operations having to do with the maintenance and servicing of operating airdromes come under the engineer of the air service command. In static situations, all construction activities and the troops to execute them may be placed under the direction of this command.

9. Engineer section, air force.—*a.* The air force engineer and his staff estimate engineer requirements of the air force and recommend assignment and employment of all engineer troops of the air force. The air force engineer also commands all engineer units not assigned to subordinate commands.

b. Staff duties of the air force engineer include—

(1) Furnishing technical advice and assistance on engineer matters to air force commander.

(2) Planning and supervising employment of all aviation engineer units assigned to air force.

(3) Reconnaissance and recommendations in conjunction with A-3 as to selection of sites for advanced airdromes.

(4) Preparation of air force engineer administrative plans, instructions, orders, and training directives.

(5) Liaison with engineers of ground forces and services of supply.

(6) Determination of engineer equipment and material requirements for contemplated air force operations.

(7) Administration of supply credits for engineer material and administration of engineer funds for air force.

(8) Inspection of engineer troops, equipment, and material.

c. Duties of the air force engineer exercised through units under his command include—

(1) Command of all engineer troops not assigned to subordinate units.

(2) Construction of field airdromes and advanced landing fields including—

(*a*) Landing field with runways, taxiways, hard standings, and dispersed installations.

(*b*) Facilities for servicing and arming aircraft.

(*c*) Storage areas for gasoline, oil, and ordnance supplies. Supplies are dispersed, concealed, and sometimes protected.

(*d*) Housing for personnel.

(*e*) Defensive installations, and protective structures if used.

(*f*) Camouflage.

(*g*) Water supply.

(*h*) Sanitary facilities.

(3) Rehabilitation of captured airdromes through employment of aviation battalions or airborne aviation battalions.

(4) Reproduction of maps, charts, and overlays, and (in conjunction with photographic squadrons) preparation of appropriate charts and target maps as required.

10. Engineer section, headquarters, air service command.—The engineer, air service command, is responsible for the expansion and maintenance of existing airdromes or air bases occupied by the air force. Duties of the engineer and his staff include—

a. Supervision of engineer activities in the air service command including—

(1) Command of engineer troops not assigned to subordinate units.

(2) Disposition of engineer troops assigned to air service command in accordance with approved plans.

(3) Establishment and operation, as necessary, of engineer supply points for camouflage and construction materials.

(4) Procurement, storage, and distribution of engineer supplies and equipment, and collection and salvage of damaged engineer equipment.

b. Maintenance and improvement of air force facilities including—

(1) Maintenance and repair of existing airdromes.

(2) Maintenance and repair of routes of communication to and from airdromes.

(3) Repair of airdromes after enemy bombardment.

(4) Assistance in preparation of plans for defense of existing airdromes against air and ground attack.

(5) Preparation of plans for demolition of existing airdromes.

(6) Construction of mine fields, road blocks, and obstacles.

(7) Maintenance of structures, water supply, and electrical installations.

c. Provision of engineering construction and maintenance services for service center area.

d. Inspection and training of engineer units attached to air service command.

e. Technical inspection and supervision of engineer installations at airdromes, air bases, and other air force installations.

f. Assistance to air force units in providing and maintaining camouflage; provision for instruction in camouflage to air force units.

g. Recommendations to A–4 on traffic regulation when required.

11. **Engineer headquarters company, air force.**—This company is attached to the air force headquarters and is operated under the air force engineer. It performs necessary drafting, designing, surveying, planning, and reproduction, and furnishes camouflage assistance in connection with the activities of the engineer aviation battalions and regiments under the air force engineer.

12. **Engineer aviation topographic company.**—This company makes aeronautical and target charts and mosaics from aerial photographs taken by photographic groups of the air force. It works as part of a team with the photographic groups and normally is assigned on the basis of one per photo group.

13. **Engineer aviation battalion.**—The battalion consists of a battalion headquarters, headquarters and service company, three lettered companies, and medical section. The battalion is the usual field operating unit. It is a balanced organization capable of executing complete construction of an airdrome, working simultaneously on all phases of construction. Each company has a considerable amount of earth-moving equipment, supplemented by equipment in headquarters and service company.

14. **Engineer aviation company.**—Separate companies are organized as required for particular missions. They are identical with the lettered company of the battalion.

15. **Engineer aviation regiment.**—The regiment is composed of three battalions and a headquarters and service company. It is designed for operation in a large theater where much work is concentrated in a small area. It acts as a depot or pool for additional equipment which may be sent to individual battalions as the need arises. The battalions within regiments are identical with other engineer aviation battalions.

16. **Engineer camouflage battalion, air force.**—In a theater of operations this unit furnishes technical assistance, supervision, and control for the camouflage activities of all air force units in connection with the design, planning, and execution of their camouflage

works. It fabricates and supplies camouflage materials from local sources and carries on experimentation for new camouflage methods. The battalion is responsible for the indoctrination and training of all air force units in connection with camouflage policy, discipline, practices, and techniques. It accomplishes these responsibilities by means of schools and field demonstrations and by preparation and dissemination of publications and posters.

17. Airborne engineer aviation battalion.—These troops with their light equipment perform the pioneer work of repair and rehabilitation of advanced airdromes which are not accessible by overland movement of standard equipment. Airborne aviation engineers are covered in detail in chapter 15.

18. Units other than aviation engineers.—General service engineer units or other general and special engineer units may be assigned to airdrome construction. In rear areas, general service units may take over construction and maintenance from aviation engineer units to allow the latter to move to forward areas. Combat engineer troops may expect assignments to construct advanced landing fields.

CHAPTER 3

EQUIPMENT

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Concrete equipment 29
Compressed air equipment 30
Water supply equipment 31
Electric lighting equipment 32
Miscellaneous 33
Hand tools 34
Transportation 35
Weapons 36

19. General.—The equipment issued to aviation engineers has been selected for its usefulness in airdrome construction and maintenance. Proper use of this equipment is essential to the fulfillment of the mission. The equipment consists principally of standard commercial items of heavy earth-moving and compaction machinery, together with other items also issued to general service and combat engineers. Special equipment not organically issued to troops may be obtained from the theater of operations depots. This equipment is largely heavy construction equipment capable of providing various types of surfaces for runways. It consists of asphalt and concrete plants and auxiliary equipment. Requirements in different theaters of operation vary; therefore, each battalion may not have identical equipment.

20. Maintenance.—*a.* Maintenance of equipment cannot be stressed too highly. *The battalion cannot operate unless its equipment is in working condition.* There must be continuous first echelon and preventive maintenance by all drivers and equipment operators, frequent command inspections, periodic technical inspections, and regular and systematic second echelon maintenance. *Some form of daily motor inspection and servicing is necessary.* All personnel who are drivers, operators, mechanics, or supervisors must become thoroughly familiar with FM 25-10.

b. Since engineer aviation units frequently operate in remote areas, maintenance normally performed by higher echelons is often accomplished within the unit. Two items of equipment are provided specifically for maintenance and repair facilities. They are the shop, motorized, type A, and the shop, motorized, type B. Although these shops are designed to work together, complementing each other, they may be separated if necessary.

(1) Each shop can furnish its own power but outside power may be used when available. Facilities are provided whereby three-phase power of either 208, 220, 380, or 440 volts may be used by proper switching arrangements. Outside 110-volt a-c power may be used for most equipment.

(2) The two shops are well equipped to make repairs to equipment of engineer aviation units. Proper training of maintenance personnel is essential. Maintenance should be placed in competent supervisory hands and every effort made to stress precise workmanship. The best repair facilities are worthless without proper supervision, training, and mechanical ingenuity on the part of the operating personnel.

21. Earth-moving equipment.—*a*. This equipment consists of tractors, scrapers, shovels, and rooters. The tractor (80 dbhp, Diesel powered) with angledozer is a high production earth mover designed for rough, heavy work. Particularly adapted to drifting material a short distance, it smoothes the way for graders, scrapers, and trucks. The quantity of earth moved is much greater when the dozing is done on a downgrade. The tractor has a rear-mounted dual drum power-control unit for the operation of scrapers, cranes, and rooters. In soil which is hard to load into scrapers, the tractor may be used as a pusher in order to fill scrapers to capacity. Among the varied tasks which the tractor with angledozer can perform are clearing, pioneering, sidehill cutting, leveling, snow removal, loading trucks from ramps, and backfilling.

b. The tractor-drawn scraper (scraper, self-loading, towed type, cable operated, 8-yard) is designed for medium hauls from 200 to 3,000 feet. For maximum production the scraper should be loaded as it moves downgrade. Scrapers should not be used in rocky material as the cutting edge will last only a few hours under such conditions.

c. Two sizes of shovels are issued to the battalion. On is a 3/8-yard truck-mounted shovel, while the other is a 1/2-yard crawler type. The 3/8-yard shovel (crane, truck-mounted, with pile driver, 3/8-yard dragline, and trailer) can be moved quickly for short distances with its trailer, on which are loaded the attachments for converting it to a dragline, pile driver, clamshell, or crane. The 1/2-yard shovel (shovel, gas engine, ½-yard) is also convertible but is not so mobile as the truck-mounted shovel. These shovels may be used for loading sand or gravel from stockpiles into trucks, and have sufficient power for excavating when the soil is not laden with boulders or frozen. Under average conditions the ½-yard shovel can deliver 40 cubic yards of dirt per hour and the ⅜-yard shovel can deliver 35 cubic yards. They are well adapted for all types of light earthwork under all conditions. The dragline bucket is useful for opening trenches, loading trucks, and for dirt work where it is possible to cast the spoil. The clamshell bucket is also useful for ditching, unloading sand and gravel, and handling stockpile material. The clamshell and dragline may be used for excavating under water. The pile driving leads can handle piling 14 inches in diameter and about 25 feet long when the piling is to be driven into the ground which is level with the shovel tracks. The pile driver hammers on the ⅜-yard and ½-yard shovels weigh 1,200 and 1,800 pounds, respectively.

d. The cable-operated road rooter is designed to loosen soil for quick loading of power scrapers or for other grading and mixing equipment. It is also used for clearing and grubbing operations and for loosening and opening pavements other than concrete.

22. Grading equipment.—Graders are of two types: motorized and drawn. The motorized grader (grader, motorized, Diesel), is a high speed maintenance unit which can perform finished grading. Together with the scrapers it can be used for maintaining roads, sloping, constructing drainage ditches, and keeping cut and fill in proper condition. It may also be used for light scarifying work. The towed grader (grader, road, towed, leaning wheel), a lighter machine, is used for rough grading, for pioneer road work, and for preliminary ditching.

23. Compaction equipment.—For compaction, several types of rollers are used. The sheepsfoot roller (roller, sheepsfoot, two drums in line) is used to compact cohesive soils, soil-cement mixtures, and some bituminous mixtures. As the roller passes over loose material the projecting "feet" apply weight to loose particles, forcing them downward to a compacted seat. This operation is repeated until all of the material has been packed and the marks made by the feet are but shallow indentations. This operation is known as "rolling out." The marks left by the feet are then kneaded into the surface and a smooth, firm base obtained by using the rubber-tired roller (roller, towed, rubber-tired, 13 wheels). The wheels of this roller operate independently of each other in a wobbly fashion off an eccentric axle, and the front wheels are alined to cover the spacing between the rear wheels. For final compacting and to finish the surface, the smooth-surfaced rollers are used (roller, 5- to 8-ton, tandem two-axle; and roller, 10-ton, three-wheel). The sheepsfoot and tandem rollers are weighted by filling drums or wheels with water or sand, and the rubber-tired roller is weighted by loading sandbags onto the body.

24. Bitumen and water distributing equipment.—*a.* Bituminous materials are usually shipped in drums but may be shipped by tank car, barge, or boat. In each battalion, tanks (tank, 1,500-gallon, with steam coils, trailer-mounted) are specially equipped to heat bitumen in drums, thus emptying the drums and providing a supply of hot bitumen. Circulating hot water or steam to heat the bituminous materials in the 1,500-gallon tank or in the tank cars is furnished by an asphalt heater (heater, asphalt, trailer type). The liquid bitumen may be distributed in large quantities in two ways. The usual method of distribution is with the bituminous distributor (distributor, asphalt and bituminous, 1,250-gallon, trailer-mounted). This distributor applies fluid bitumen over large areas. For small work and for maintenance patching, the asphalt kettle (kettle, asphalt, trailer-mounted) is used. This kettle, with a capacity of 165 gallons, has a motor-driven pump and a hand-spraying attachment.

b. Water is distributed for construction in two ways. One method is with the same 1,500-gallon trailer tank used for heating drums of bitumen. A pump (pump, water, with distributor, trailer-mounted) is attached to the trailer tank. Water may also be spread by attaching the pump just mentioned to water tanks placed on trucks (tank, 750-gallon, two compartments, skid-mounted).

25. Stabilizing equipment.—For subgrade and base stabilization the following pieces of equipment are used:

Plows for mixing (tractor, disk, and gang).
Motor grader, for scarifying and mixing (grader, motorized Diesel).
Harrows, for mixing (harrow, spike tooth).
Rotary tiller, for completing the mixing (mixer, rotary tiller).
Sheepsfoot roller, for compaction (roller, sheepsfoot, two drums in line).
Fine grading with the motor graders using the blades and flat-wheel rollers (roller, 10-ton three-wheel; also roller, 5–8 ton tandem two-axle).

During these operations water is used in quantity (tanks, 750-gallon, two compartments, skid and tank, 1,500-gallon, with steam coils, trailer-mounted).

26. Drainage equipment.—The ditching machine (machine, ditching, digging depth 8 feet 3 inches; 24 inches width) is used to dig narrow trenches in soil for such purposes as subdrains, burying conduit or pipe, and latrines. Hand excavation in places inaccessible to the ditcher is supplemented by compressed air or portable gas hammers. Motor graders are used to cut small open V-ditches. A shovel, dragline, scraper, or angledozer may be used for large channels. Diaphragm pumps may be used to remove seepage water from excavations, or to pump collected drainage water from sumps at sites protected by dikes or levees. Other pumps are available in theater headquarters depots.

27. Aggregate production plant.—A plant for crushing, screening, and washing rock, of 150 tons per hour capacity, and a gravel crushing and screening plant of 100 tons per hour capacity are included in the heavy construction equipment normally issued to theater headquarters depots. These prepare aggregate for all base and surface courses including concrete and bituminous paving as well as for backfilling subdrains, maintenance stockpiles, and miscellaneous construction.

28. Asphalt plant.—*a. Equipment.*—The following heavy construction equipment is located in theater headquarters depot stocks. It is issued to battalions as needed.

Units per set	
1	Conveyor, belt, transfer, 24 inches by 57 feet
1	Dryer, aggregate, dual drum, travel or central plant, 80 to 150 tons per hour, trailer-mounted
1	Elevator, aggregate, bucket, inclosed
1	Finisher, asphalt, crawler-mounted, 12-foot paving width
2	Heater, asphalt, three-car, 42 horsepower boiler, trailer-mounted
2	Loader, bucket, three cubic yards per minute, crawler-mounted
1	Mixer, asphalt, travel or central plant, 110 to 200 tons per hour
	Piping, for boilers, dryer, tanks, etc.
1	Pump, asphalt, with distributor attachments, trailer-mounted
2	Tanks, asphalt storage, steel, 4,000-gallon, bolted, with steam coils

b. Function.—The primary function of this equipment is rapid construction of stabilized base or surface course mixtures by mixing in place on the runway or mixing at a central location. The equipment will produce stabilized mixtures of natural materials, soil-cement mixtures, and bituminous mixtures.

c. Mixed-in-place operations.—For mixing in place the crawler-mounted bucket loader and trailer-mounted mixer are joined to form a travel plant. This unit mixes water and cement, or bitumen with aggregate laid in windrows on the runway. The mixing process is continuous down the length of the windrows. The crawler-mounted finisher may follow the traveling mixer to spread and finish bituminous mixtures. In an emergency wet windrowed aggregate may be dried by combining the crawler-mounted bucket loader and trailer-mounted dryer into a traveling dryer unit to precede the mixing unit. If conditions permit, the best method of drying with aggregate is to dry in place with grader manipulation.

d. Central plant-mix operations.—All of the pieces in the set may be assembled into a central plant to produce any type of bituminous mixture.

29. Concrete equipment.—The concrete mixer (mixer, 14 cubic feet trailer-mounted) serves all the needs for concrete at an airdrome other than for the placing of concrete runways. It may be used for motor repair shop floors and grease pits, for footings, for foundations for lathes and delicate meteorological instruments, for retaining walls and small dams, and for catch basins and bridge abutments. Equipment for constructing concrete runways, issued normally to the theater stockpile, consists of a 34 cubic foot paver, a batching plant, steel forms, form tamper, spreader, finisher, and hand finishing tools.

30. Compressed air equipment.—The compressed air units (compressor, air, motorized), consisting of 105 cubic feet per minute compressors mounted on trucks, have handy tools for speeding up work. Air tools furnished with the units include chain saws, circular saws, paving breakers, diggers, spades, and moil points, tampers, and nail drivers. Two tools can be operated at once. However, two large tools can be operated only intermittently because they will exceed the 105 cubic feet per minute capacity. When using the drills the larger bits should be put on first and progressively smaller ones later as depth is attained. The clay spades are useful for excavating in hardpan and also are excellent vibrators for concrete.

31. Water supply equipment.—*a.* During early operations water is pumped into tanks and trucked or dragged to the places needed. Two-inch pumps (pump, 2-inch centrifugal, 10,000 gallons per hour) are available for lifting water, and water tanks (tank, 750-gallon, skid-mounted) may be used for transporting it. The tanks may also be used for storage and transport of fuel oil and gasoline.

b. The 4-inch diaphragm pump is available for pumping very muddy water and for places where pumping is intermittent with a large amount of air. It is mounted on two steel wheels and has three

25-foot lengths of hose, one intake, and two discharges. At 50-foot head it puts out 6,000 gallons per hour.

c. The water purification unit consists of a pumping and treatment section, a filter section, three 3,000-gallon canvas storage tanks, and accessories including facilities for testing water.

32. Electric lighting equipment.—*a.* The 3-kilowatt set in the company (electric light equipment, 3-kilowatt) and the 5-kilowatt set in the battalion (electric light equipment, 5-kilowatt) are used for outside illumination. Floodlights (light, flood, 150-watt) issued to each company and to the battalion are used with the sets on runway sites and other construction points. Also, carbide floodlights (floodlight, carbide) are furnished to each company. They may be used in widely separated places but are subject to weather conditions.

b. Illumination in buildings is limited to the light furnished by lanterns. In areas where blackouts are not necessary three types of lanterns are used. They are the portable electric lantern, the gas lantern, and the standard kerosene lantern.

33. Miscellaneous.—*a. Camouflage equipment.*—Issued to battalion headquarters and service company, the tools and equipment include a paint agitator, several paint-spraying sets, and other small hand tools.

b. Plow, tractor.—This is used to break the ground where fills are to be made in order to consolidate the fill with the existing earth. It is also used to loosen earth in grading operations and to assist mixed-in-place operations.

c. Sweeper, rotary, tractor-operated.—Issued as part of the battalion special equipment set. It is an attachment for the front of the gasoline tractor (30 dbhp) with a power take-off at the side of the tractor. The fiber broom is operated by a shaft and chain drive. It is used for removing sand, dust, gravel, and light snow from roads and runways, for cleaning, and in preparation for bitumen application.

d. Tractor, rubber-tired, 30 dbhp.—A prime mover for light and medium road working equipment.

e. Trailers, low bed.—The 8-ton trailer is used for hauling tractors and the 16-ton trailer for general transportation. Sixteen-ton trailers are issued to the company for hauling its D–7 tractors.

f. Crane, tractor-operated.—Mounted on two rubber tires and operated by the drum control mechanism mounted on the rear of a tractor. Leverage applied through a system of cables permits a 20-ton lift. The boom of the crane is 20 feet long with a 5-foot overhang at the end. The crane is used for heavy work. It is not adaptable to lifting and swinging work because it is hard to turn with a load suspended. The overhang makes it useful for such work as removing an engine from an airplane.

34. Hand tools.—Lettered companies are equipped with demolition, carpenter, and pioneer sets identical with those issued to combat companies.

35. Transportation.—*a.* The engineer aviation battalion is not motorized. The personnel can be carried in one move provided all vehicles are used, but the prime movers must be sent back to shuttle the equipment forward.

b. Transportation consists of personnel carriers, combat vehicles, and heavy equipment prime movers or carriers. These are issued as follows (T/BA 5):

Vehicles	Issued to—		Purposes
	Ltr Co.	Bn H&S Co	
Car, half-track, M2	1	1	Reconnaissance, security, and combat.
Truck, ¼-ton, 4 x 4	4	4	Reconnaissance and transportation.
Truck, ¾-ton, 4 x 4, carry-all.	--------	1	Reconnaissance, carry-all.
Truck, ¾-ton, 4 x 4, command.	1	1	Reconnaissance and command.
Truck, ¾-ton, 4 x 4, weapons carrier.	--------	3	Cargo, weapons carrier.
Truck, 2½-ton, 6 x 6, cargo	--------	--------	Kitchen and supply, prime mover for two trailers, 1-ton, two-wheel tank (250 gallons water).
Truck, 2½-ton, 6 x 6, dump, with winch.	8	10	Earthwork, personnel, and prime mover.
Truck, 2½-ton, 6 x 6, tank, 750-gallon.	--------	1	Carrying water.
Truck, 4-ton, 6 x 6	3	5	Earthwork and prime mover.
Truck, 6-ton, 6 x 6 prime mover, with winch.	--------	3	Cargo, and prime mover.

c. Personnel vehicles and all trucks up to 2½-ton can move at normal convoy speeds and can make long motor marches. However, prime mover equipment such as the 4-ton and 6-ton trucks, the distributor, the concrete mixer, the rooters, and the 30-horsepower tractor (on trailer) must move at slower speeds and cannot make such long marches. A group even more difficult to move includes the heavier equipment such as the scrapers, graders, and D–7 tractors. They must travel at very slow speeds and are restricted to short marches. Finally there is a fourth group which is usually moved only in the vicinity of construction jobs. Trailers with shovels, track-laying tractors not on trailers, smooth rollers, ditching machines, and tractor cranes are normally shipped by rail when moved from one job to another.

36. Weapons.—Each lettered company and headquarters and service company is issued one half-track car. The half-track is equipped with two air-cooled machine guns, one .50 caliber and one .30 caliber. Each company has one 37-mm antitank gun and four .50 caliber antiaircraft machine guns. Personnel are armed with pistols, carbines, M1 rifles, and bayonets (T/BA 5).

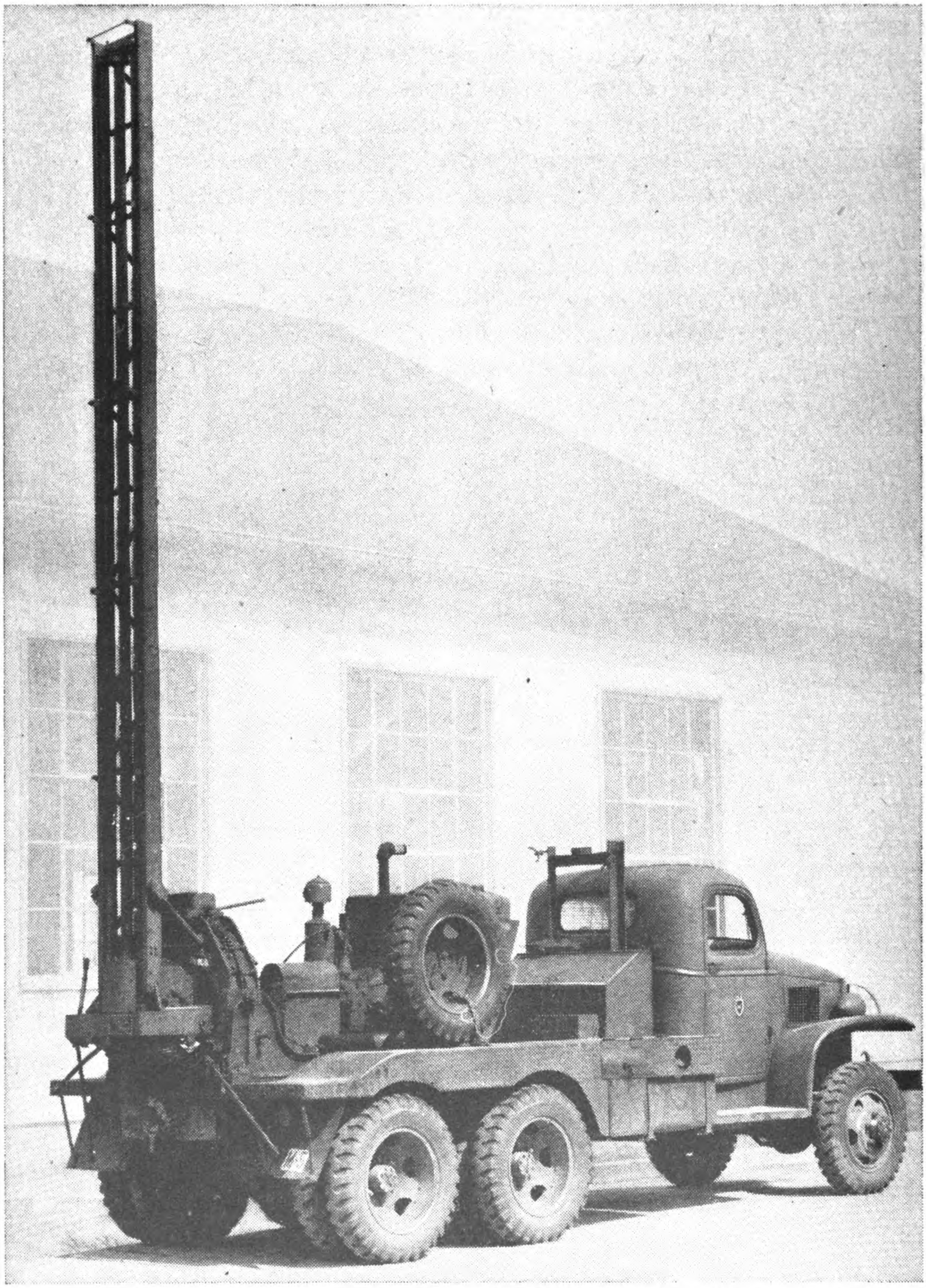


FIGURE 3.—Auger, earth, gas, motorized. Weight 12,800 pounds on 2½-ton truck, 6 x 6. Furnished with bits 12 inches to 24 inches in diameter. Used for demolition work, post holes, etc.

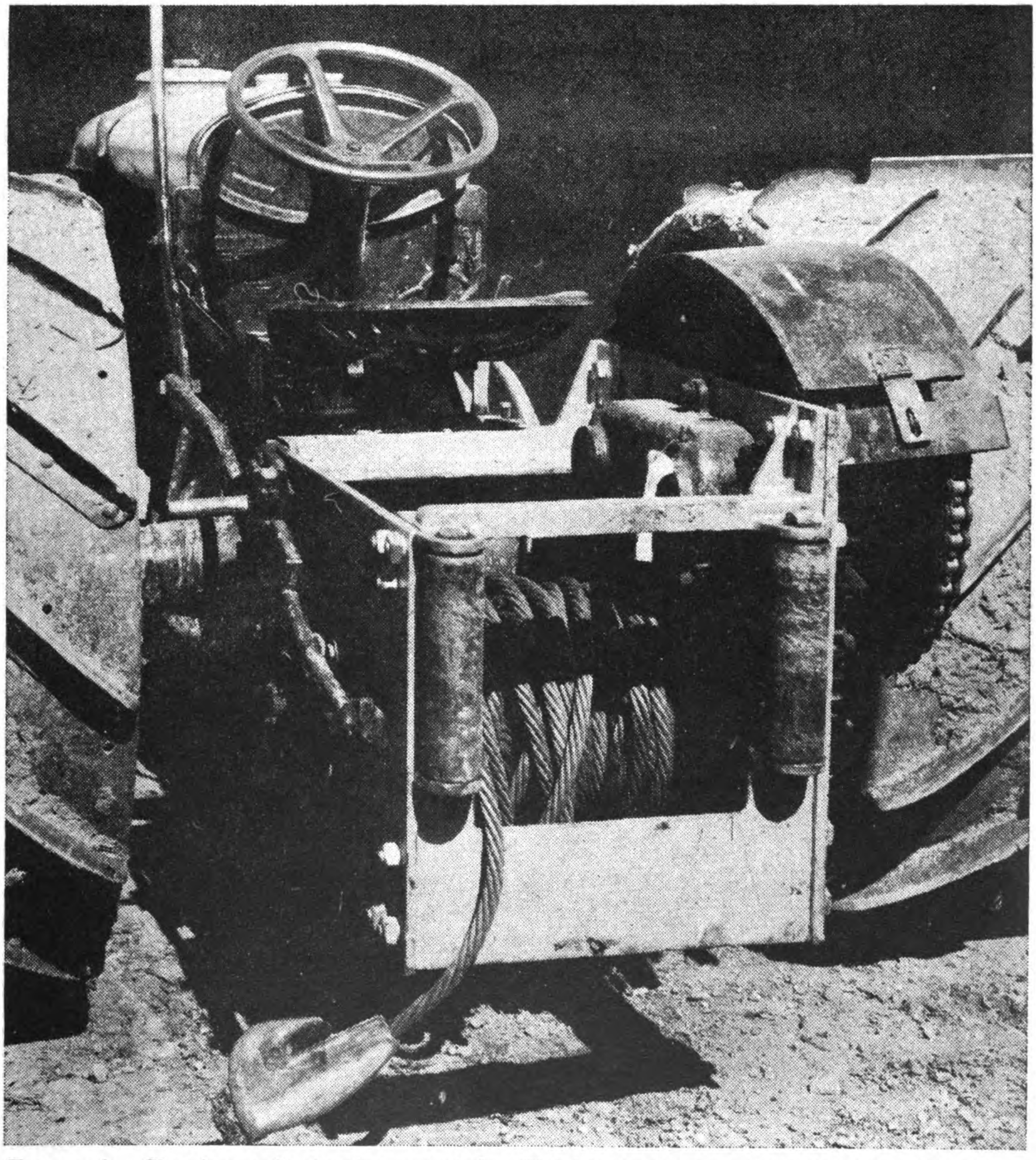


FIGURE 4.—Clearing unit, tractor-mounted. Weight 14,000 pounds. Tractor with winch for pulling stumps.

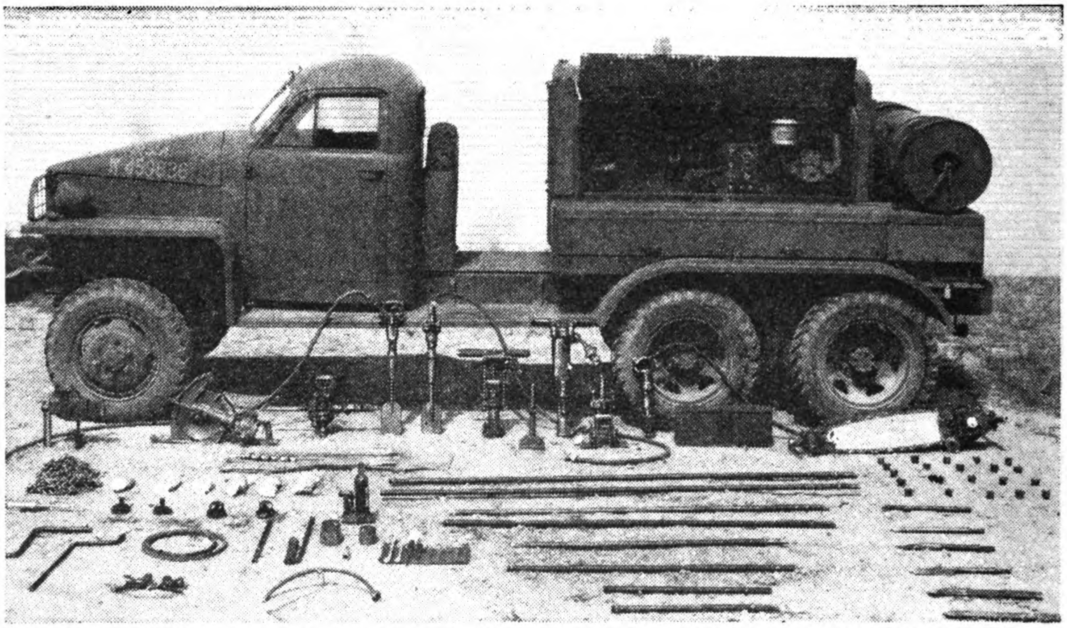


FIGURE 5.—Compressor, air, motorized, 105 cubic feet per minute. Weight 12,180 pounds on 2½-ton truck, 6 x 6. Air unit for pneumatic tools, circular saw, clay spade, jack hammer, drills, and pavement breaker.

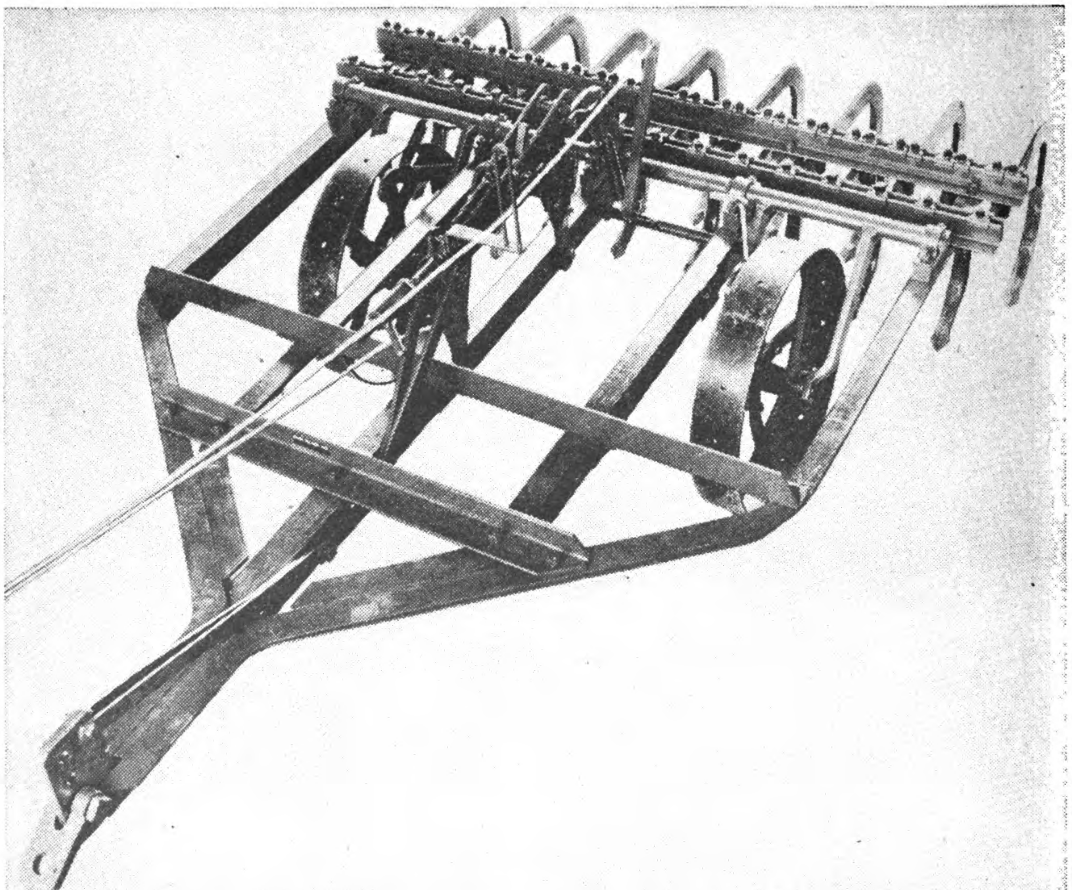


FIGURE 6.—Cultivator, chisel, 12-inch spacing, 8 feet width. Weight, 2,370 pounds. Tractor-drawn. To loosen, break up, and mix soil after scarification, and for progressive stabilization.

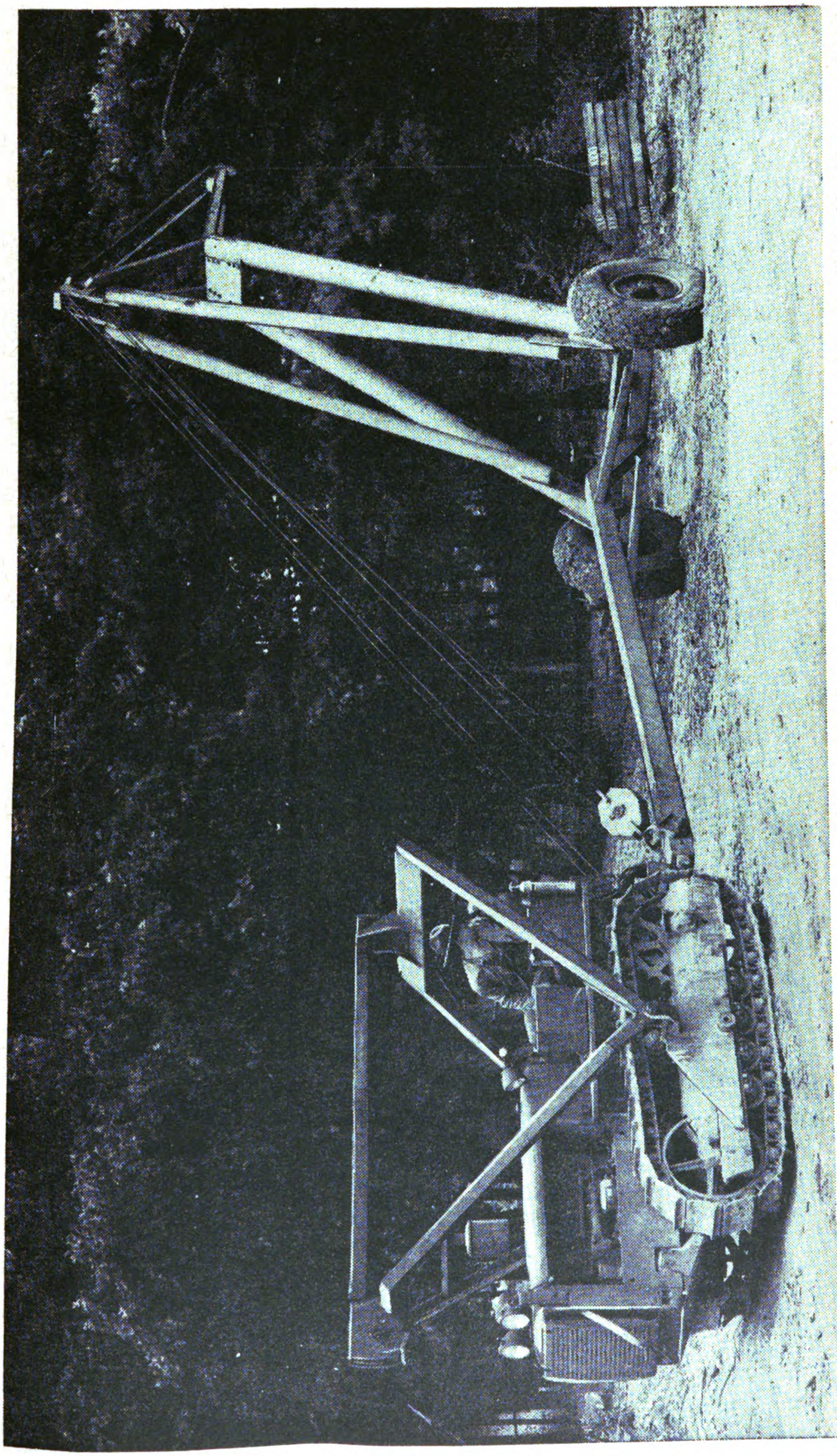


FIGURE 7.—Crane, tractor-operated, 20-ton, 20-foot boom. Weight 7,300 pounds. Power unit required: tractor with double drum power control. For heavy lifts on equipment, supplies, airplanes, bombs, and debris. Crane is normally operated by a D-7 tractor.

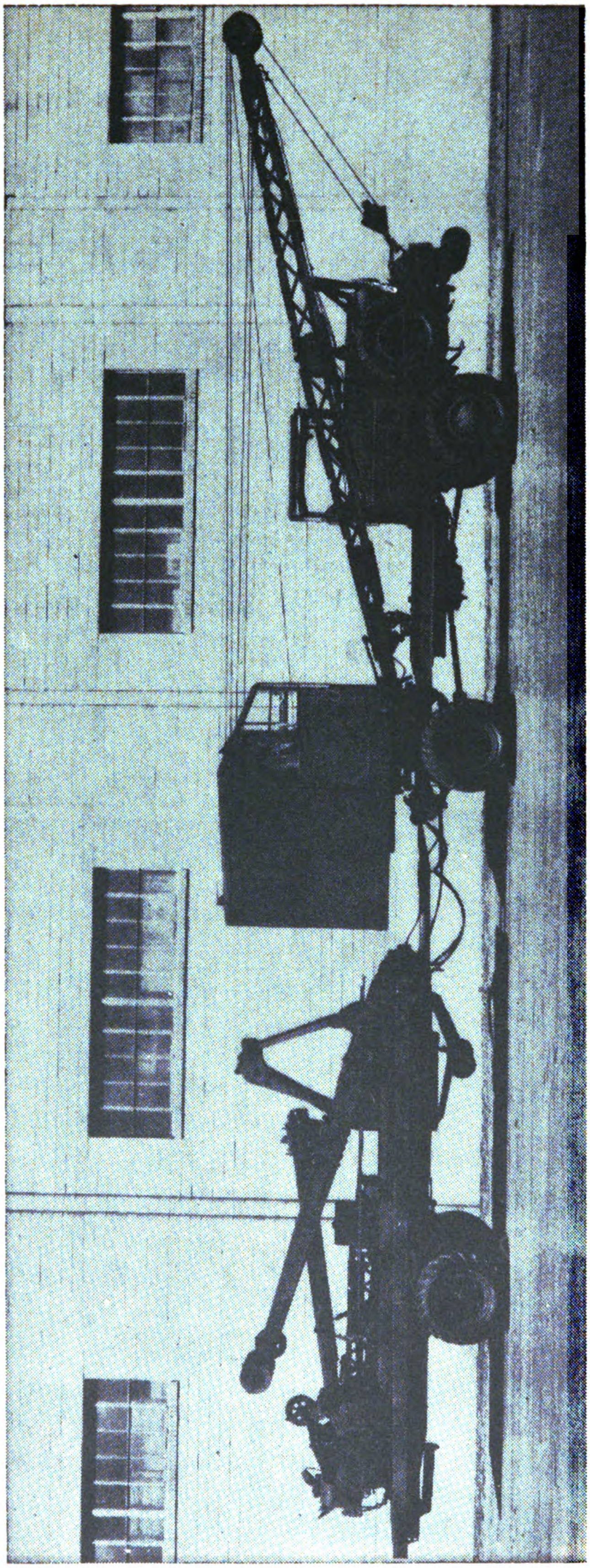


FIGURE 8.—Crane, truck-mounted, with pile driver, ⅜-yard dragline, and trailer. Weight 35,680 pounds complete with crane boom, clamshell, dragline bucket, shovel, pile driver, and two-wheel trailer. For moving earth, construction material, and equipment.

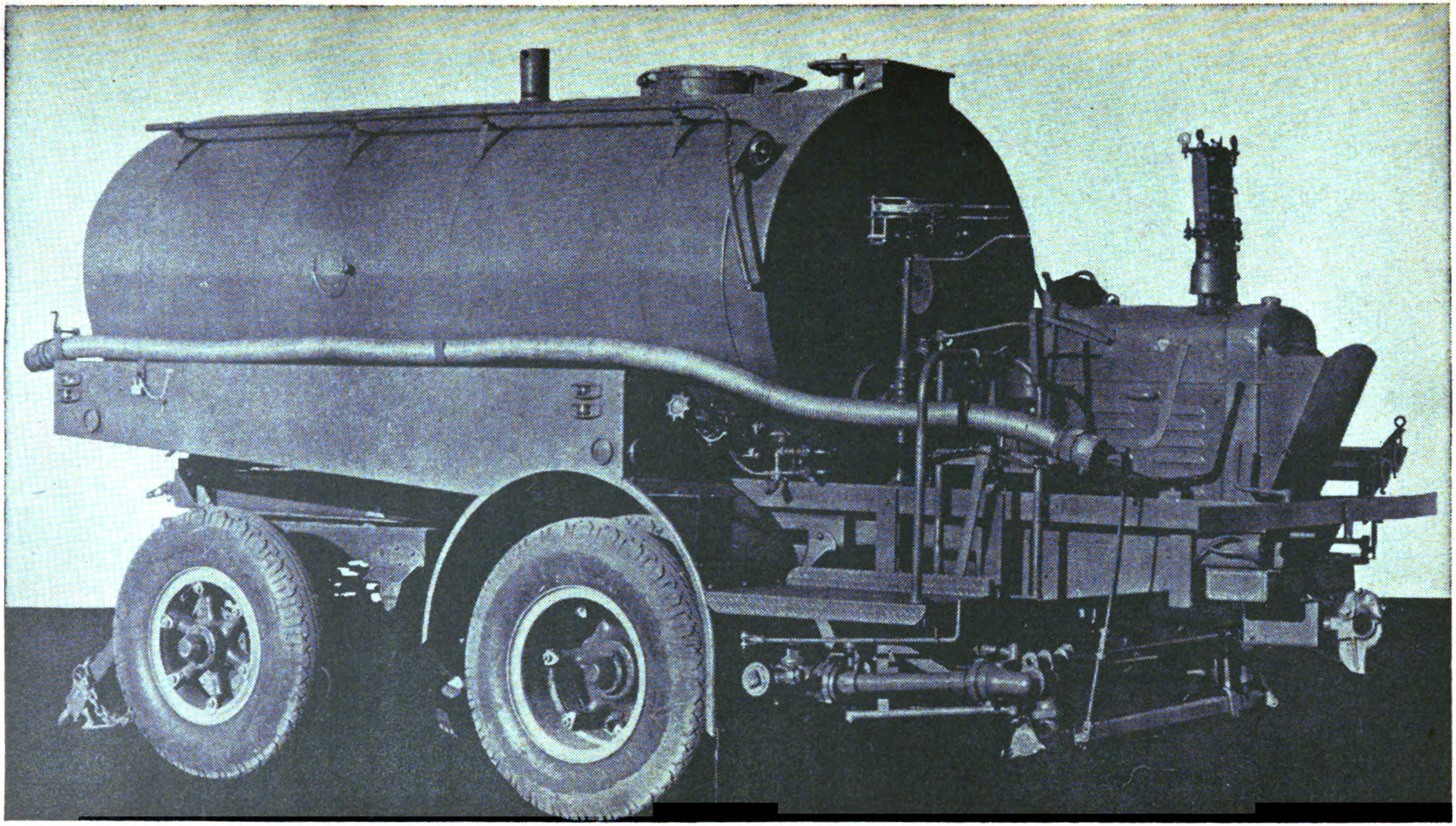


FIGURE 9.—Distributor, bituminous, 1,250-gallon, trailer-mounted. Weight 10,720 pounds empty, 20,980 pounds loaded. For heating, transporting, transferring, distributing, or hand spraying materials for bituminous surfaces.

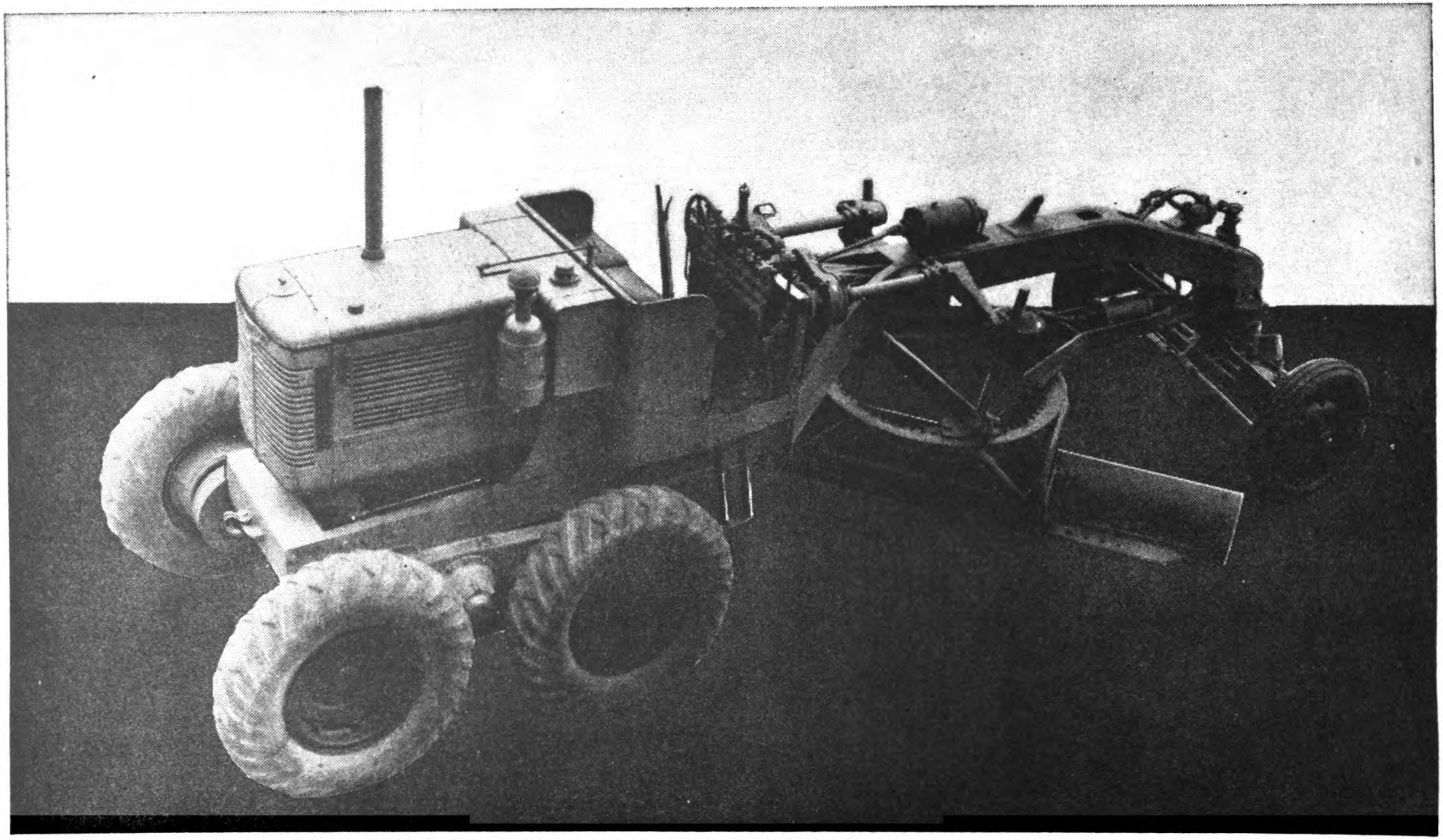


FIGURE 10.—Grader, road, motorized, Diesel, 12-foot moldboard. Weight 22,150 pounds. For construction and maintenance of runways and roads. Equipped with floodlights for night work.

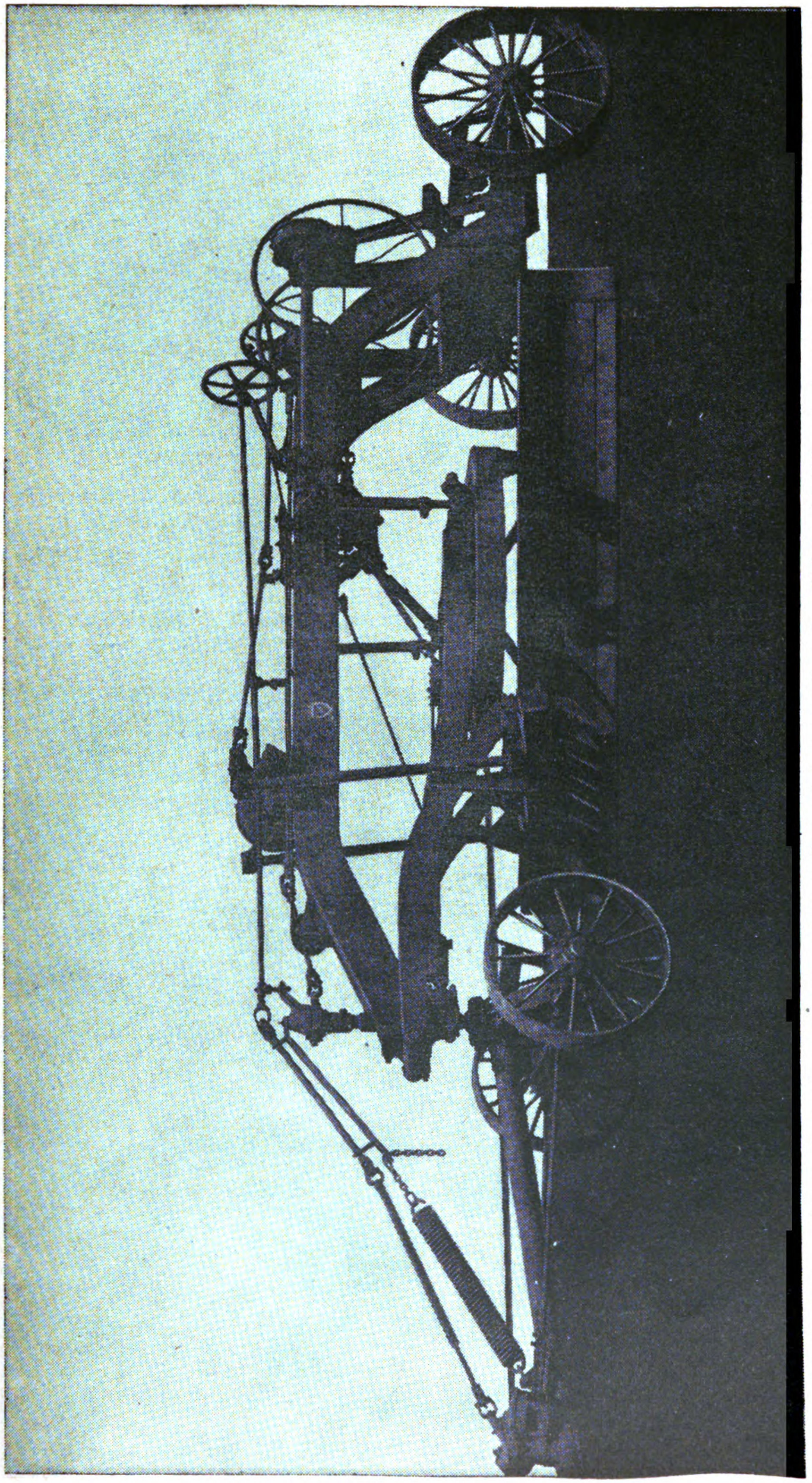


FIGURE 11.—Grader, road, towed, leaning wheel, hand-controlled, 12-foot moldboard. Weight 12,175 pounds. Requires 60 dbhp. To construct or widen temporary new roads, or to widen existing roads, and for maintenance of surfaces.

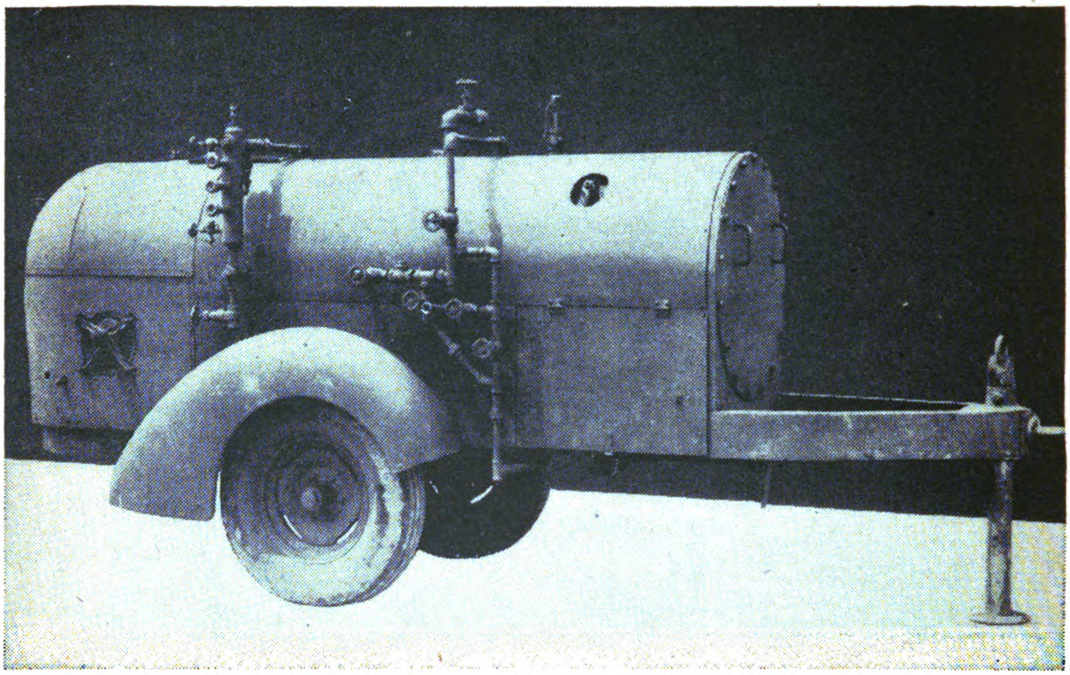


FIGURE 12.—Heater, asphalt, two-car, 28-horsepower boiler, trailer-mounted. Weight 6,400 pounds. Steam generating plant to heat bituminous material in tank cars or in the 1,500-gallon, trailer-mounted tank. May also be used for steam cleaning equipment.

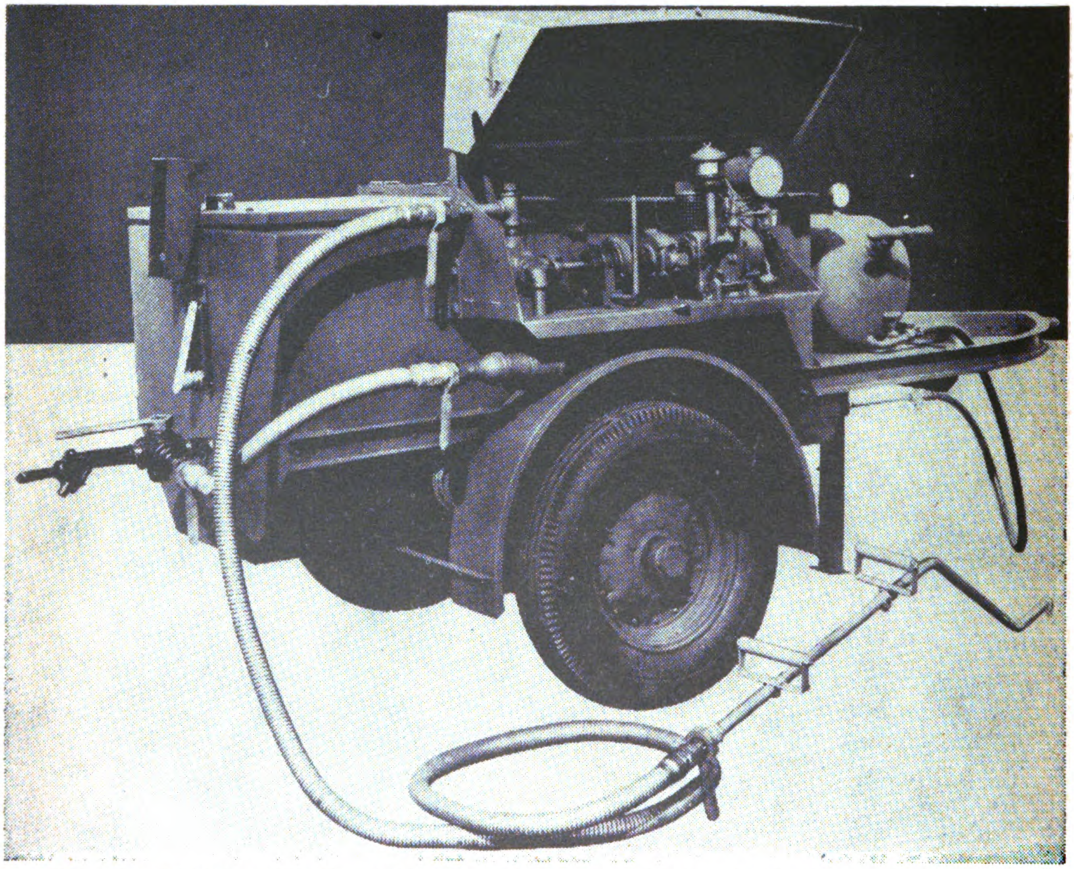


FIGURE 13.—Kettle, asphalt, 165-gallon, with motor-driven hand spray, trailer-mounted. Weight 1,500 pounds. For transporting and heating bituminous materials for repairing roads and runways.

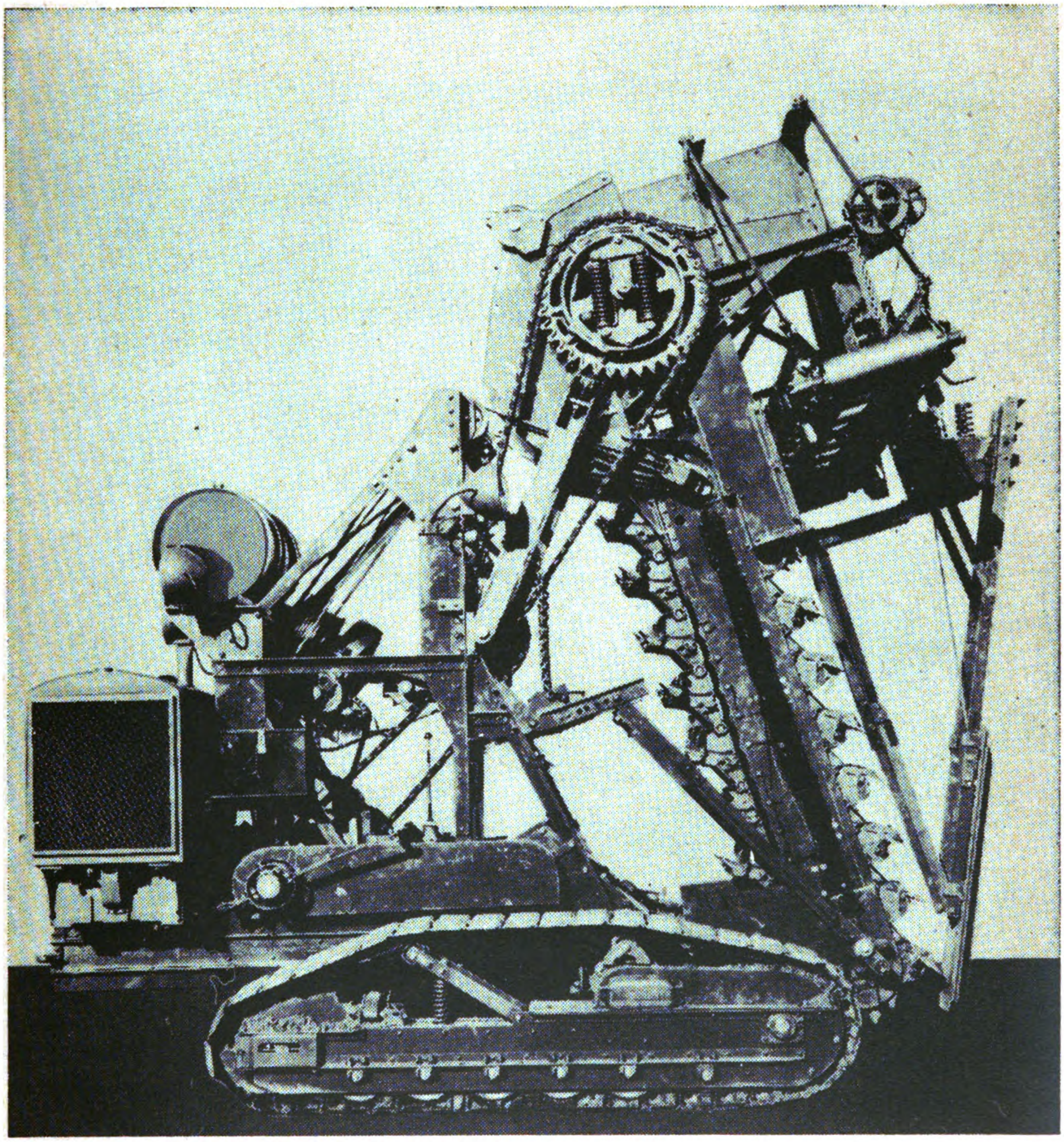


FIGURE 14.—Machine, ditching, ladder type, digging depth 8 feet 3 inches, 24-inch width, crawler-mounted. Weight 23,000 pounds. For excavating trenches for fortifications, drainage, and utilities.

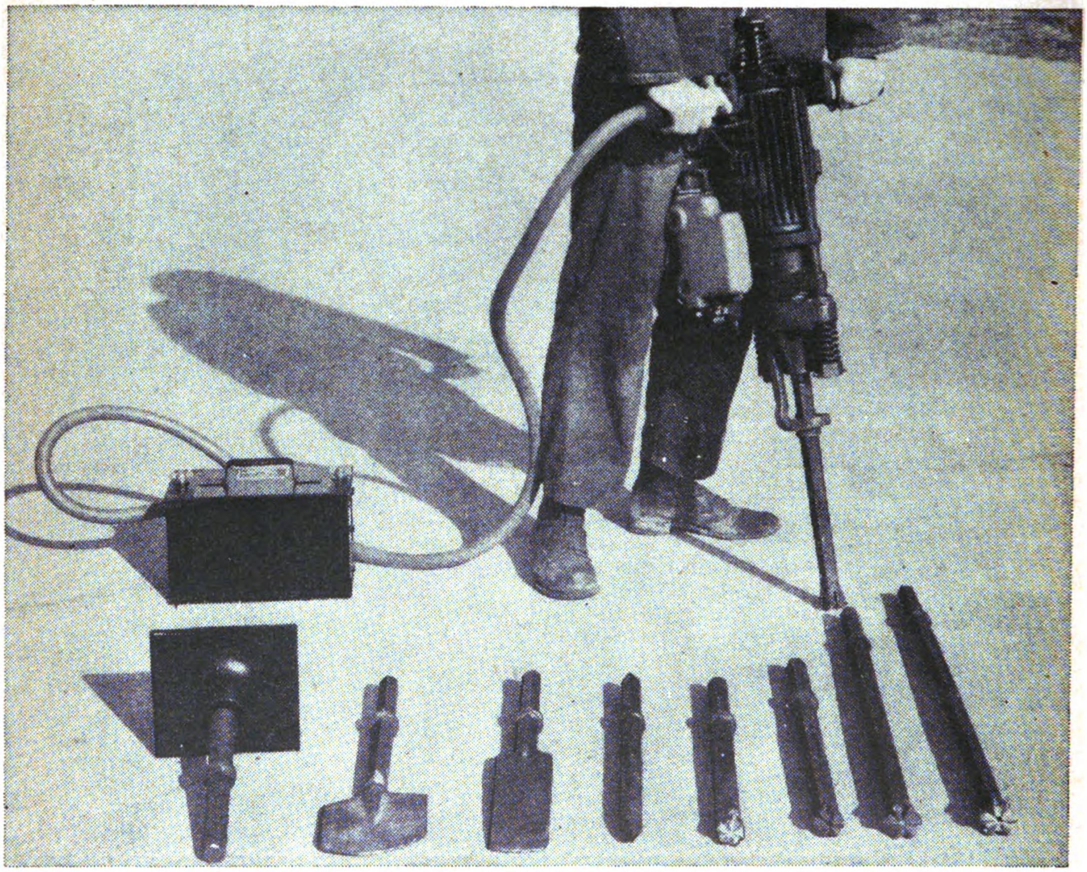


FIGURE 15.—Hammer, gas, portable. Weight 100 pounds. One-cylinder gas engine, hand-operated, for breaking rock and pavement. Fitted with attachments: paving breaker, tamper, spades, and drills.

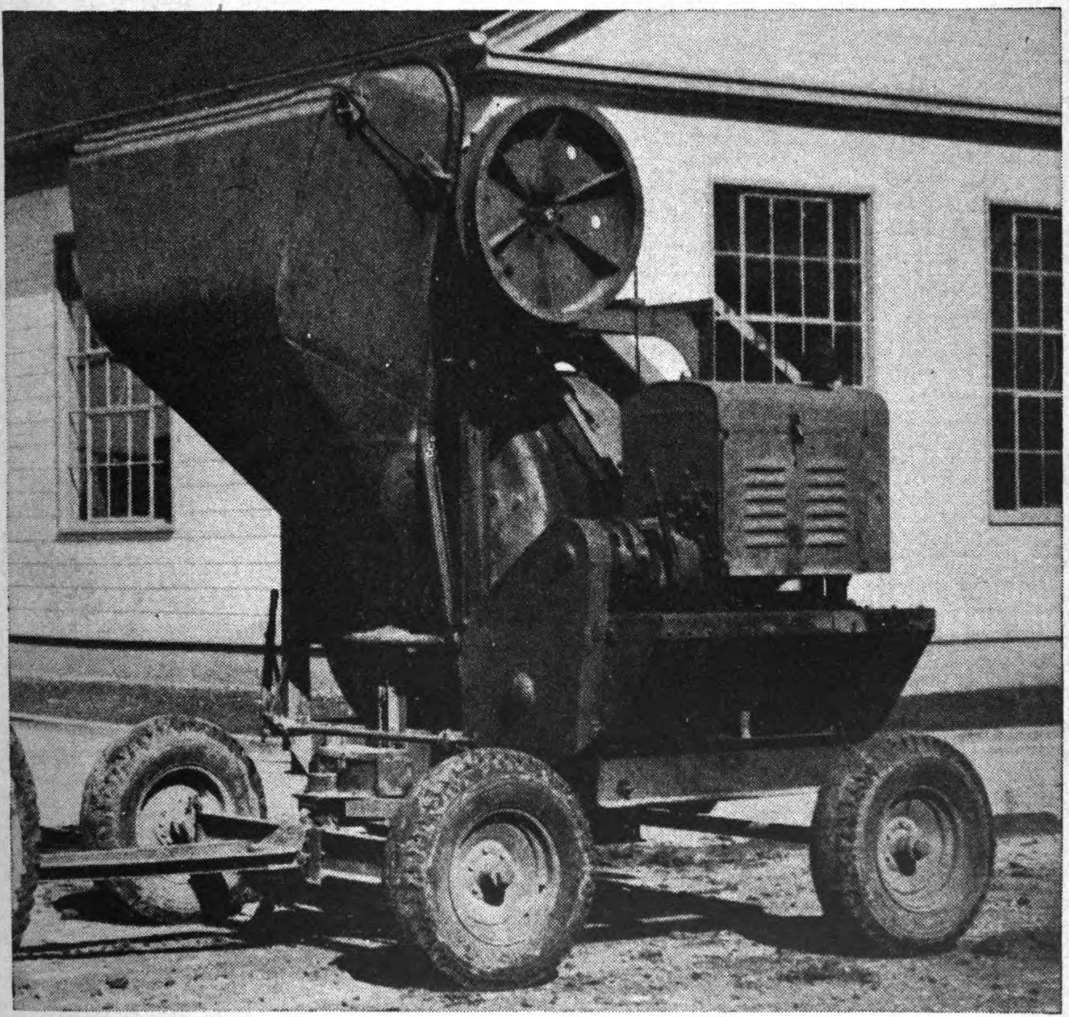


FIGURE 16.—Mixer, concrete, 14 cubic feet, trailer-mounted. Weight 6,200 pounds. Self-powered, gas-operated, truck-drawn. For mixing concrete for general use.

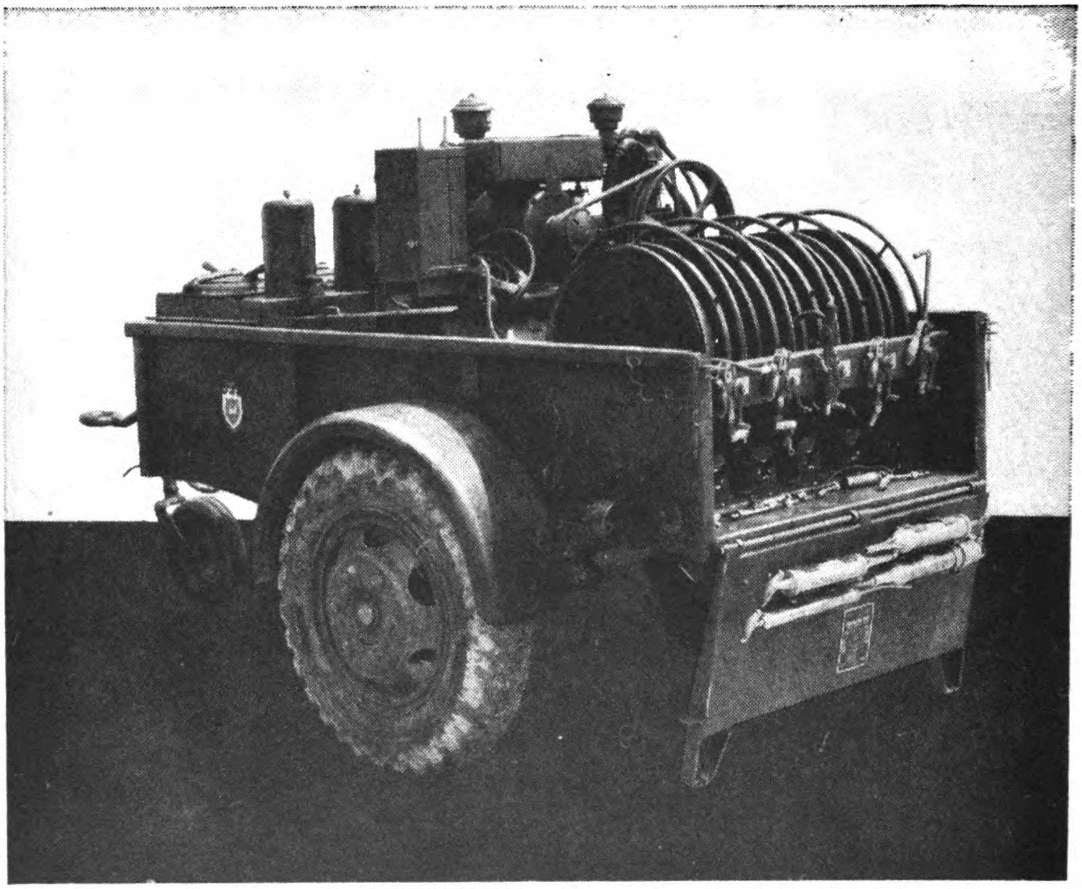


FIGURE 17.—Lubricator, trailer-mounted. Weight 3,224 pounds. For furnishing compressed air, grease, and brake fluid for equipment.

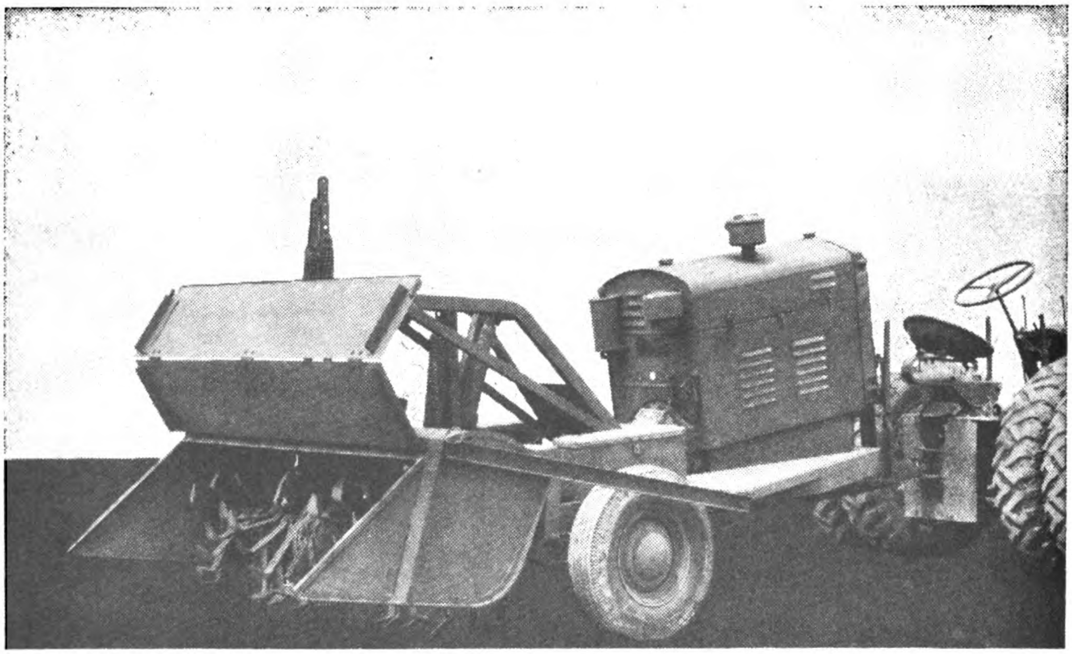


FIGURE 18.—Mixer, rotary tiller, soil stabilization, self-powered, trailer-mounted, tractor-drawn. Weight 4,625 pounds. To mix cement or asphalt with soil.

CHAPTER 10

SURFACE COURSES

Paragraphs
SECTION I. General description and basic operations 112-120
II. Detailed construction procedures 121-123

SECTION I

GENERAL DESCRIPTION AND BASIC OPERATIONS

Paragraph
Selecting type of surface 112
Surface requirements 113
Characteristics of surfaces 114
Terminology and description of materials used 115
Terms relating to bituminous construction 116
Aggregate requirements 117
Proportions of aggregate and bitumen in mixtures 118
Technical control 119
Operations in bituminous surface course construction 120

112. Selecting type of surface.—Choice of surface for runways, taxiways, and parking areas depends upon materials available (natural and commercial), nature of aircraft use to be served (light or heavy planes and temporary, intermittent, or continuous operations), time and equipment available, and prevailing weather during construction. Table XXI is a summary of primary factors to be considered in making the decision. It is also a summary of the chapter on surface courses for quick reference and review.

113. Surface requirements.—A runway surface course must be—

a. Supported by an adequate base.

b. Smooth, true to grade, and waterproof.

c. Reasonably nonskid.

d. Free of loose aggregate particles that may be whipped about by propeller blast.

114. Characteristics of surfaces.—There are three general types of surfaces besides steel (ch. 9) which may be used for airdrome pavements:

TABLE XXI.—

Type of surface course	Paragraph reference	Principal uses	Material	
			Natural	
			Name or description	Special requirements (In addition to general requirements)
Stabilized soil surface *Description.*—Mechanically stabilized using two or more blended and mixed natural materials. May be built to any thickness in layers 3 to 6 inches thick. Recommended minimum thickness of surface course is 4 inches.	121	For light airplanes and temporary or emergency use by heavier airplanes.	Caliche. Limestone. Shell. Cinders. Scoria. Shale. Disintegrated granite. Sand. Gravel. Selected soil.	Two or more natural materials are selected, proportioned, and mixed by mixed-in-place method, or by central mixing plant. Requirements for mixed material are: 1. Particle size gradation must be uniform. 2. Maximum particle size not more than ¾ inch. 3. Gradation should conform to grading B or C in table XXIV. 4. Plasticity index of fraction passing No. 40 sieve should be between 3 and 6.
Bituminous dust palliative. *Description.*—A simple surface treatment to eliminate dust and to reduce danger from loose particles on surface.	122*a*	For light airplanes and temporary or emergency use by heavier airplanes. This treatment eliminates dust and reduces danger from loose particles on surface.	None	None
Bituminous surface treatment (single or double). *Description.*—A thin surface treatment less than 1 inch thick.	122*b*, *c*, *d*	On fair bases these serve light airplanes or temporary use by heavier airplanes. On good firm bases, they serve light and medium aircraft and moderate intensity of use.	Screened gravel, crushed rock, or crushed slag.	1. Aggregate particles must be hard and durable. 2. Aggregate must be free from excess dust. 3. Particle size should range from ¾ inch to No. 10 sieve. Gradings III and IV, table XXIII are recommended.

Surface courses

Material—Continued Commercial	Equipment needed	Effect of weather on construction	Technical control required during construction	Remarks
None. (Water is needed during mixing and compaction.)	1. Can be mixed-in-place with regular battalion equipment. 2. Faster construction with traveling mixer or with central mixing plant.	Required close control of moisture content prevents mixing-in-place and compaction during wet or freezing weather.	1. Control of proportions. 2. Control of moisture during compaction. 3. Control of compaction by field density tests. 4. Check tests: Bearing ratio. Gradation. Plasticity index.	Continuous maintenance is required to keep surface tight and smooth. Surface has disadvantage of dust and loose particles, but this can be reduced by maintenance such as sprinkling or by a dust palliative such as fuel oil or fluid bituminous material. See tables XXXVII and XXXVIII.
Fluid fuel oil, or fluid bituminous materials may be used. See tables XXXVII and XXXVIII.	Regular battalion equipment.	Not constructed when surface is wet, nor when temperature is below 45° F.	Quantity applied is judged by ability of surface to absorb it.	Continuous maintenance is required.
Cutback asphalt or road tar. See tables XXXVII and XXXVIII.	Regular battalion equipment plus crushing and/or screening plant, except when aggregate is satisfactory as found.	Not constructed in wet or cold weather.	1. Control of spreading of bitumen and aggregate. 2. Control of rolling and sweeping.	Maintenance depends upon amount and kind of aircraft used. Facilities for maintenance should be continuously available.

TABLE XXI.—*Surface*

Type of surface course	Paragraph reference	Principal uses	Material	
			Natural	
			Name or description	Special requirements (In addition to general requirements)
Mixed-in-place bituminous surface. *Description.*—An intermediate quality surface, adapted to a variety of aggregates. Thickness not less than 2 nor more than 4 inches.	122*e*, *f*	Depending on quality of construction, these surfaces are generally satisfactory for light and medium aircraft and moderate intensity of use.	Screened gravel, crushed gravel, crushed rock, crushed slag, coarse sand, disintegrated granite.	1. Particle size should range from 1 inch down and conform to one of the gradings in table XXIV except a macadam type may be used as per grading II, table XXIII. 2. Plasticity index of fraction passing No. 40 sieve not greater than 6 and preferably zero.
Bituminous penetration macadam. *Description.*—A good quality surface, adapted to angular aggregate. Minimum thickness 2½ inches.	122*g*	Generally satisfactory for all but heaviest service. This surface not justified for light airplanes or temporary service.	Angular crushed rock, crushed gravel, or crushed slag.	1. Particles must be hard and durable. 2. Two sizes are required: coarse as per grading I, and fine as per grading IV, table XXIII.
Plant-mix bituminous surface. *Description.*—Cold-laid plant mix is a good quality surface. Hot-laid plant mix is a high quality surface. Thickness not less than 2 nor more than 4 inches. May be constructed in two layers.	122*h*	Generally satisfactory. Hot-laid plant mix is highest type of bituminous surface. This construction not justified for light planes or temporary service.	Screened gravel, crushed gravel, crushed slag, or crushed rock plus sand and dust. (Portland cement or hydrated lime may be used for dust.)	Particle size should range from 1 inch down and conform to one of gradings in table XXIV, preferably gradings A or B.
Portland cement concrete. *Description.*—A rigid-type pavement of highest quality. Built in one course not less than 6 inches thick.	123	Generally satisfactory for heavy planes and heavy service. This surface not justified for light airplanes or temporary service.	Gravel, crushed gravel, crushed rock, or crushed slag and sand.	1. Aggregate particles must be sound and strong. 2. Aggregate gradation must conform to requirements in table XXII. 3. Maximum size of gravel should be 2 inches.

General requirements:

1. All flexible-type bituminous surfaces must be supported by an adequate base. The base course immediately under a bituminous surface must have a bearing ratio not less than 80 percent.

courses—Continued

Material—Continued Commercial	Equipment needed	Effect of weather on construction	Technical control required during construction	Remarks
Cutback asphalt, emulsified asphalt, road tar or cutback road tar. See tables XXXVII and XXXVIII.	1. Regular battalion equipment. In some cases crushing and/or screening equipment will be needed. 2. Can be mixed-in-place with regular battalion equipment. 3. Faster construction with a traveling mixer.	Not constructed in wet or cold weather.	1. Control of aggregate quantities and gradation. 2. Field measurements of windrows and field sieve analysis of aggregate to determine proportion of bitumen needed. 3. Control of bitumen spreading. 4. Control of mixing. 5. Control of spreading and compaction.	Maintenance depends upon amount and kind of aircraft used. Facilities for maintenance should be continuously available.
Asphalt cement, cutback asphalt, emulsified asphalt, or road tar. See tables XXXVII and XXXVIII.	Regular battalion equipment plus crushing and screening plant.	Not constructed in wet or cold weather.	1. Control of spreading aggregate. 2. Control of bitumen spreading. 3. Control of compaction.	Maintenance facilities should be continuously available.
Asphalt cement, cutback asphalt, or emulsified asphalt. See tables XXXVII and XXXVIII.	Asphalt plant in heavy construction equipment set, plus regular battalion equipment.	Not constructed in wet or cold weather.	1. Control of aggregate gradation. 2. Control of proportions. 3. Control of mixing. 4. Control of spreading and compaction.	Maintenance facilities should be available.
Portland cement, or high early strength cement.	Concrete plant in heavy construction equipment set, plus regular battalion equipment.	Wet and cold weather retards construction. Freezing weather generally stops construction.	1. Control of aggregate gradation and quality. 2. Control of proportions. 3. Control of mixing, placing, finishing, and curing.	Maintenance facilities should be available.

2. All surfaces must be true to line and grade, reasonably smooth and reasonably nonskid. No loose particles that may be whipped about by propeller blast should be permitted on a runway surface.

a. Mechanically stabilized surface course.—This type is similar to stabilized soil base (par. 92). It uses local materials only; commercial material is not required. It is relatively simple to build with regular engineer aviation equipment. Construction is generally suspended during wet or freezing weather. Continuous maintenance is required and amount of maintenance increases with aircraft use. Except for temporary or emergency use, it is not suited for fighters and bombers. It has the disadvantage of loose fragments and dust, although this can be reduced by maintenance (ch. 11).

b. Bituminous surface courses.—Most bituminous surfaces can be built with regular engineer aviation equipment; however, for some types, special equipment not assigned to battalions is needed for fast construction. Construction methods are quite flexible, hence several grades of bituminous material and a wide variety of local aggregate can be used. Bituminous construction lends itself to stage improvement. Any required thickness up to 4 inches can be built in layers, either initially, or later during improvement of the airdrome. Greater thickness than 4 inches is not advisable; thicker base should be built instead. Bituminous surfaces are relatively impervious and effectively protect base and subgrade from surface water. Amount of maintenance required depends upon thickness of surface course, quality of construction, and amount of aircraft use. Surface treatments are primarily for light aircraft or for temporary use by heavier airplanes. Surfaces 2 to 4 inches thick are suitable for general use. For thicknesses greater than 2 inches there is considerable variation in speed of construction depending on quality. High quality surfaces such as asphaltic concrete are very serviceable. Prolonged wet weather and temperatures below 45° F. generally require suspension of construction operations.

c. Concrete.—Concrete slabs are highly serviceable and require little maintenance. They are constructed in one course or layer not less than 6 inches thick. Good quality aggregate is required. Special equipment not issued to battalions is needed. Construction is relatively slow. Protection from freezing is necessary during setting and early hardening.

115. Terminology and description of materials used.—*a. Aggregates.*—The following terms are used to describe mineral aggregates for surface course construction:

(1) *Macadam aggregate.*—This is a term describing crushed stone, crushed slag, or crushed gravel which is screened to a uniformly coarse size. When such aggregate is compacted, the void spaces between particles are relatively large.

(2) *Graded aggregate.*—This term describes a mineral aggregate in which there is a continuous grading in the sizes of mineral fragments from coarse to fine, the coarser sizes being many times larger than the finer sizes.

(3) *Coarse and fine aggregate.*—The term "coarse" is applied to a graded mineral aggregate in which the particles are larger than ¼-inch diameter. A No. 3 sieve (¼-inch) is often used to separate coarse and fine aggregate.

(4) *Dense and open graded aggregate.*—The term "dense" is applied to a graded aggregate which contains sufficient dust or mineral filler (generally more than 5 percent passing No. 200 sieve) to reduce all voids in the compacted aggregate to exceedingly small size. It may be either coarse or fine graded. The term "open" applies to a graded aggregate containing little or no dust (generally less than 5 percent passing the No. 200 sieve).

b. Bituminous materials (see app. IV for specific data).—The principal bituminous materials for surfacing airdrome runways are asphalt and tar products. Asphalt (designated AC meaning asphalt cement) is derived from petroleum or from natural asphalt deposits. Tar (designated RT meaning road tar) is derived from coal. Both asphalt and tar are called bitumen. Each of these materials is available in several grades or forms convenient for construction.

(1) *Methods of making fluid.*—Asphalt and tar at ordinary temperatures are too hard (viscous) to mix or spray. For construction operations they must be made temporarily fluid, and subsequent to construction they must again resume their original stable conditions. There are three methods of making bituminous materials temporarily fluid:

(*a*) *By heating.*—If not overheated, they return to original form upon cooling.

(*b*) *By blending or thinning with appropriate solvents.*—During and after construction operations the solvent evaporates, leaving the original bituminous material.

1. Asphalts are blended (cut-back) with petroleum distillates. When naphtha is used as solvent the products are called rapid-curing (RC) cut-back asphalts. There are six grades of RC cut-backs; RC–0, RC–1, RC–2, RC–3, RC–4, RC–5. The only difference between them is the proportion of solvent and asphalt in each. RC–0 has most solvent and is fluid at ordinary temperatures. RC–5 has least solvent and is only semifluid at ordinary temperatures, therefore some heating is also required to render it sufficiently fluid for construction operations. When kerosene is used as a solvent the asphaltic products are called medium curing (MC) cut-back asphalts. There are six grades of MC cut-backs: MC-0, MC-1, MC-2, MC-3, MC-4, MC-5. Their uses and characteristics are similar to the RC cut-backs except that the solvent evaporates more slowly than naphtha. There is a third series of asphaltic products known as slow-curing (SC) materials, but these are not contemplated for use in field airdrome work unless they are more conveniently available than RCs or MCs. When SCs are used the procedure and quantities employed are smiliar to those for MCs.

2. Tars are blended or thinned (cut-back) with solvents distilled from coal to produce a series of cut-back road tars designated RTCB.

Caution: To avoid fires and explosions, all cut-backs must be handled with extreme care when being heated. Open flames, lanterns, sparks or fire of any kind must not be allowed near the domes of tank cars or near manholes or other openings in the top of distributors or storage tanks because of the danger of explosion of accumulated solvent vapors. Asphalt and tar should not be mixed.

(*c*) *By emulsification.*—Bituminous materials ordinarily do not mix with water, but by the addition of a small amount of chemical (emulsifying agent) it is possible to effect a temporary mixture of approximately equal parts of water and asphalt in the form of an emulsion. Emulsified asphalts are very fluid at ordinary temperatures. They can be readily sprayed and mixed with aggregate. After spraying or mixing the water and asphalt separate (the emulsion breaks) and the water evaporates leaving the asphalt. Asphalt emulsions (designated AE) are available in three grades:

1. Rapid setting: RS-1.
2. Medium setting: MS-1, MS-2, MS-3.
3. Slow setting: SS-1, SS-2.

Caution: Because asphalt emulsions contain nearly as much water as asphalt, it is generally necessary in making a mixture to use about 40 percent more emulsion than if asphalt is used in any other form. Freezing damages asphalt emulsions.

(2) *Manufacture.*—Figure 114 illustrates the general plan of manufacture of asphaltic products from crude petroleum.

(3) *Shipping.*—Bituminous material is shipped in various ways.

Barrels may be used for hard asphalt cement. Steel drums of 55-gallon capacity may be used for any bituminous material. Except for emulsions and very fluid products, heating is necessary to empty the drums. The 1,500-gallon trailer with steam coils is provided for this purpose. Bituminous materials may also be shipped in bulk by tanker, barge, railroad tank car, or tank truck. For short hauls the tanks may be insulated to keep the material hot and fluid for pumping. If not unloaded before cooling, the tank must be equipped with steam coils for reheating at the unloading point.

c. Cement.—Standard portland cement is used for concrete construction. It is generally delivered in cloth or paper bags ready for use. Each bag contains 94 pounds of cement and has 1 cubic foot loose volume. A barrel of cement contains four bags and weighs 376 pounds. High early strength cement is similar to standard portland cement except that it hardens and develops strength much faster.

Caution: Cements must be kept dry until used.

d. Concrete admixtures.—Calcium chloride is sometimes used with standard portland cement and occasionally with high early strength cement to accelerate the rate of setting and hardening of concrete during curing. When so used it is called an admixture.

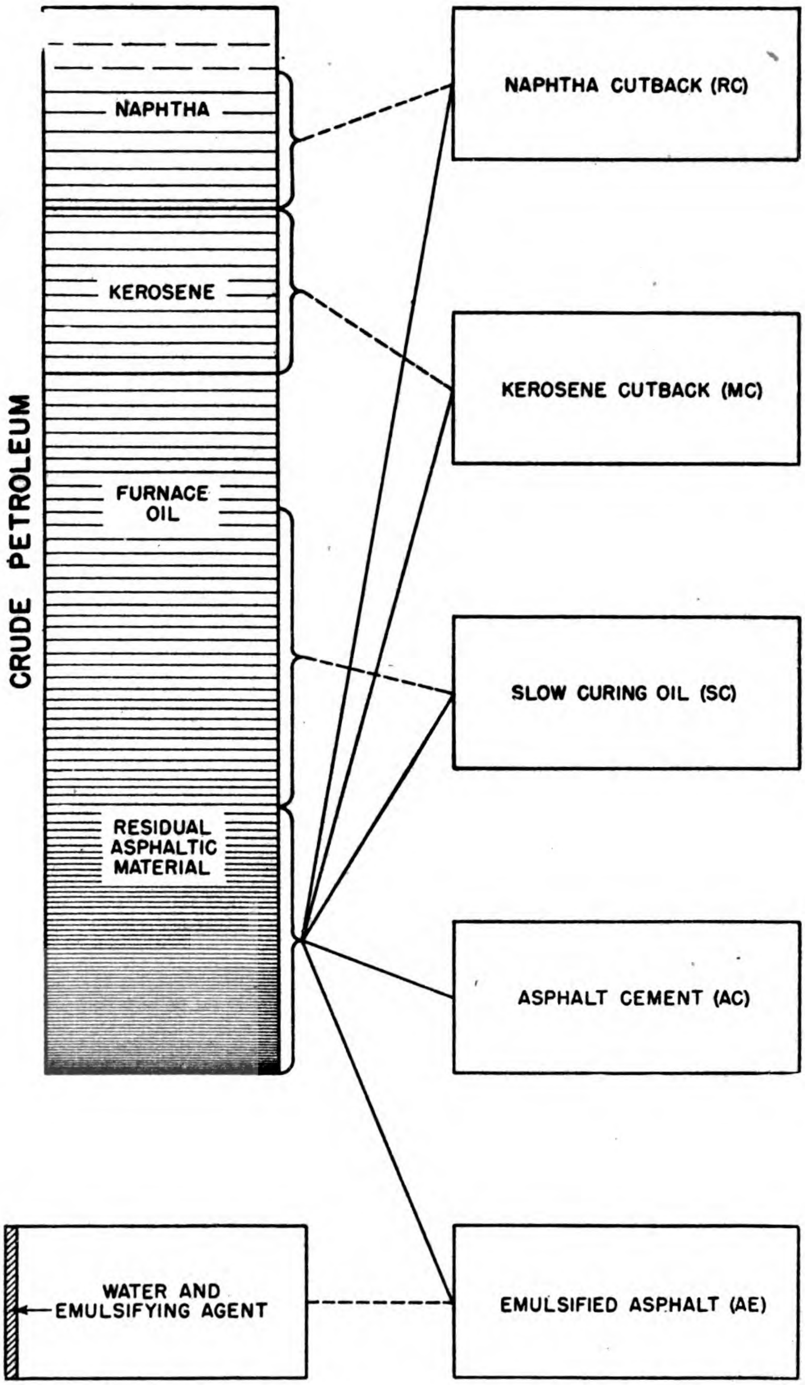
116. Terms relating to bituminous construction.—*a. Penetration construction.*—This is a general method of construction in which bituminous material is combined with aggregate by spraying the bituminous material onto compacted aggregate where it flows around the particles and penetrates into the voids between particles of aggregate.

b. Mixed-in-place construction.—This describes a process of mixing bituminous material into mineral aggregate in place on the runway. It may be done by two methods:

(1) Using a distributor to spread the bituminous material over the aggregate at a predetermined rate and mixing on the runway by a combination of harrow, cultivator, grader, and rotary tiller.

(2) Using a traveling mixer which picks up the aggregate from the runway, adds bituminous material and mixes the two in one continuous operation.

c. Plant-mix construction.—This refers to the mixing of bituminous material and aggregate in a plant set up at some convenient or central location. Finished mix is transported to and spread upon the runway. Mixing plants consist of portable units which may be assembled in several combinations. After the plant is set up it is often called a stationary plant or central plant to distinguish it from a traveling mixer.


CRUDE PETROLEUM
NAPHTHA
KEROSENE
FURNACE OIL
RESIDUAL ASPHALTIC MATERIAL
NAPHTHA CUTBACK (RC)
KEROSENE CUTBACK (MC)
SLOW CURING OIL (SC)
ASPHALT CEMENT (AC)
WATER AND EMULSIFYING AGENT
EMULSIFIED ASPHALT (AE)

(NOT DRAWN TO SCALE)

FIGURE 114.—General make-up of petroleum asphalt produc

d. Cold-laid mixtures.—These are mixes which may be spread and compacted at normal atmospheric temperatures. Some cold-laid mixtures may be prepared in a heated condition, but they need not be compacted while hot.

e. Hot-laid mixtures.—These are plant mixes which must be spread and compacted while in a heated condition.

f. Prime coat.—This refers to an initial application of fluid bituminous material to any base course, either as a dust palliative (dust layer), or preparatory to the construction of any type of bituminous surface course. The objects of priming are to penetrate the base so as to plug voids, to coat and bind dust and loose mineral particles, and to promote adhesion between the base and surface courses.

g. Bituminous surface treatments.—These are simple bituminous surface courses usually less than 1 inch thick. Ordinary construction procedure is to spread bitumen by spraying from a distributor and cover with a spread of mineral aggregate.

h. Seal coat.—This is a bituminous surface treatment applied as a finish to any bituminous surface course, primarily for the purpose of hardening and waterproofing or sealing the surface. Aggregate cover is often added to the seal coat to improve skid resistance and to improve color and light reflection. The seal coat may also be used as the adhesive for various texturing materials for camouflage (see ch. 14).

117. Aggregate requirements.—*a. Concrete construction.*—Coarse and fine aggregate for concrete construction must be composed of sound, durable, clean, uncoated particles. The fine aggregate (sand) must contain not more than 3 percent by weight of silt and clay and it must be free of organic matter. Dirty sand that is otherwise satisfactory may be cleaned by washing. Field tests for cleanliness and organic matter are given in paragraph 50, appendix III. Recommended grading requirements are given in table XXII.

b. Bituminous construction.—(1) *Surface treatment and penetration macadam.*—Table XXIII shows satisfactory aggregate gradations and typical uses in bituminous construction. To resist surface wear, all aggregate must be composed of sound, durable particles.

(2) *Mixed-in-place and plant-mix.*—Table XXIV and figure 115 show five aggregate gradations that have stable characteristics. The five grading bands in table XXIV and figure 115 overlap, thus permitting selection of a proper aggregate from a wide range, running from generally coarse to generally fine. The only restriction that should be applied in the use of aggregate falling within any one of the bands shown is that at least 10 percent of the total aggregate

pass the No. 4 sieve and be retained on the No. 10 sieve. The amount of bitumen required for any of the mixes shown in table XXIV may be estimated from curves in paragraph 118.

118. Proportions of aggregate and bitumen in mixtures.—*a. General.*—Satisfactory bituminous mixtures of any type can be obtained only through proper proportioning of the bitumen to the available aggregate. Some analysis of the aggregate must be made before the proper amount of bituminous material suitable for that particular aggregate can be determined. Under military conditions, analysis of an aggregate is often made by very hasty methods or by inspection only. However, the more complete the analysis the more precise the bituminous determination, and the better the final mixture is likely to be. The following "rules of thumb" are helpful:

TABLE XXII.—*Grading requirements for concrete aggregates*

Coarse aggregate		Fine aggregate	
Sieve designation	Percent passing	Sieve designation	Percent passing
Maximum size [1]	97–100	No. 4	95–100
One-half maximum size	40–70	No. 10	55–85
No. 4	0–6	No. 40	15–40
		No. 100	2–7

[1] Maximum size is generally 2 inches for concrete paving.

TABLE XXIII.—*Aggregate gradations and use in bituminous surface course construction*

Standard sieves	Aggregate designation					
	I [1]	II [2]	III [3]	IV [4]	V [4]	VI [4]
4-inch						
3½-inch						
2½-inch	100					
2-inch	90–100					
1½-inch	35–70	100				
1-inch	0–15	90–100	100			
¾-inch		40–75	90–100	100		
½-inch	0–5	15–35		90–100	100	
⅜-inch		0–15	30–65	40–75	85–100	100
No. 4		0–5	5–25	5–25	10–30	85–100
No. 10			0–5	0–5	0–10	10–40
No. 20						0–3

USES

[1] Coarse aggregate for penetration macadam surface course. Particles must be angular.

[2] Mixed-in-place, macadam aggregate type. Particles must be angular.

[3] Bituminous surface treatment. Particles may be either angular or rounded, angular preferred.

[4] Fine aggregate or screenings for penetration macadam. Particles must be angular.

Bituminous surface treatment. Particles may be either angular or rounded, angular preferred.

Mineral cover for seal coats. Grading VI is preferred for airdromes. Particles may be either angular or rounded.

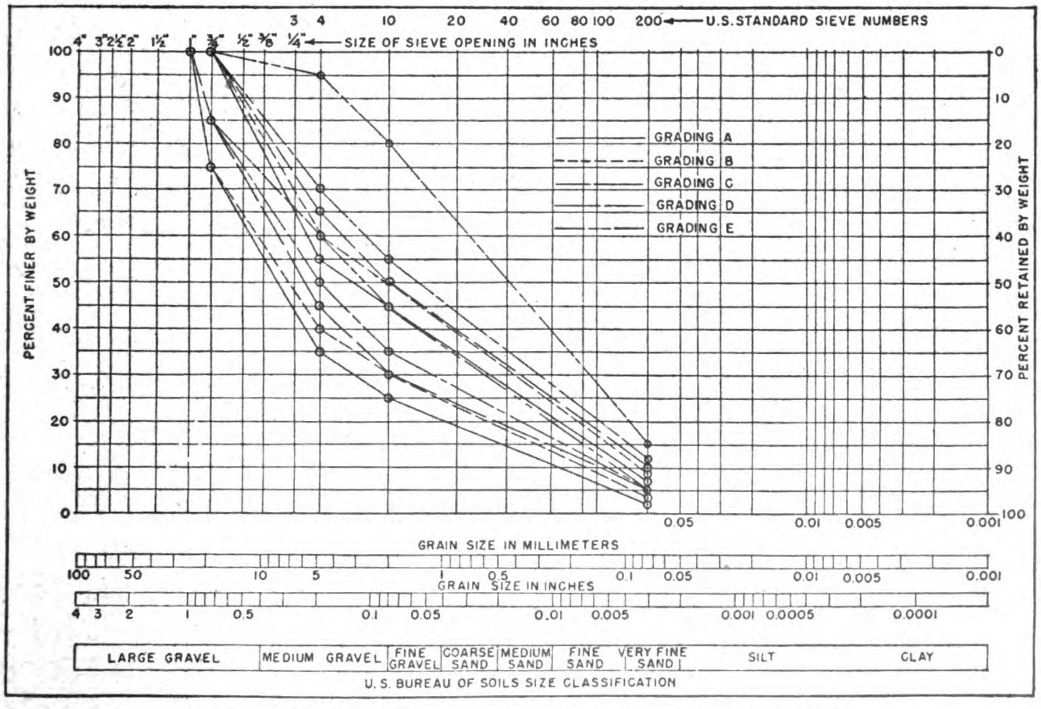


FIGURE 115.—Graph of aggregate gradations shown in table XXIV.

TABLE XXIV.—*Typical aggregate gradings for mixed-in-place or plant-mix bituminous surface courses*

Size of sieve passing	Percentage by weight				
	Aggregate designation				
	A	B	C	D	E
1-inch	100	100	100	100	100
¾-inch	75–100	75–100	85–100	85–100	85–100
No. 4	35–55	40–60	45–65	50–70	60–95
No. 10	25–45	30–50	30–50	35–55	45–80
No. 200	2–7	3–8	5–10	5–12	5–15

Material passing No. 40 sieve must not have a plasticity index greater than 6 and preferably 0 (see app. III).

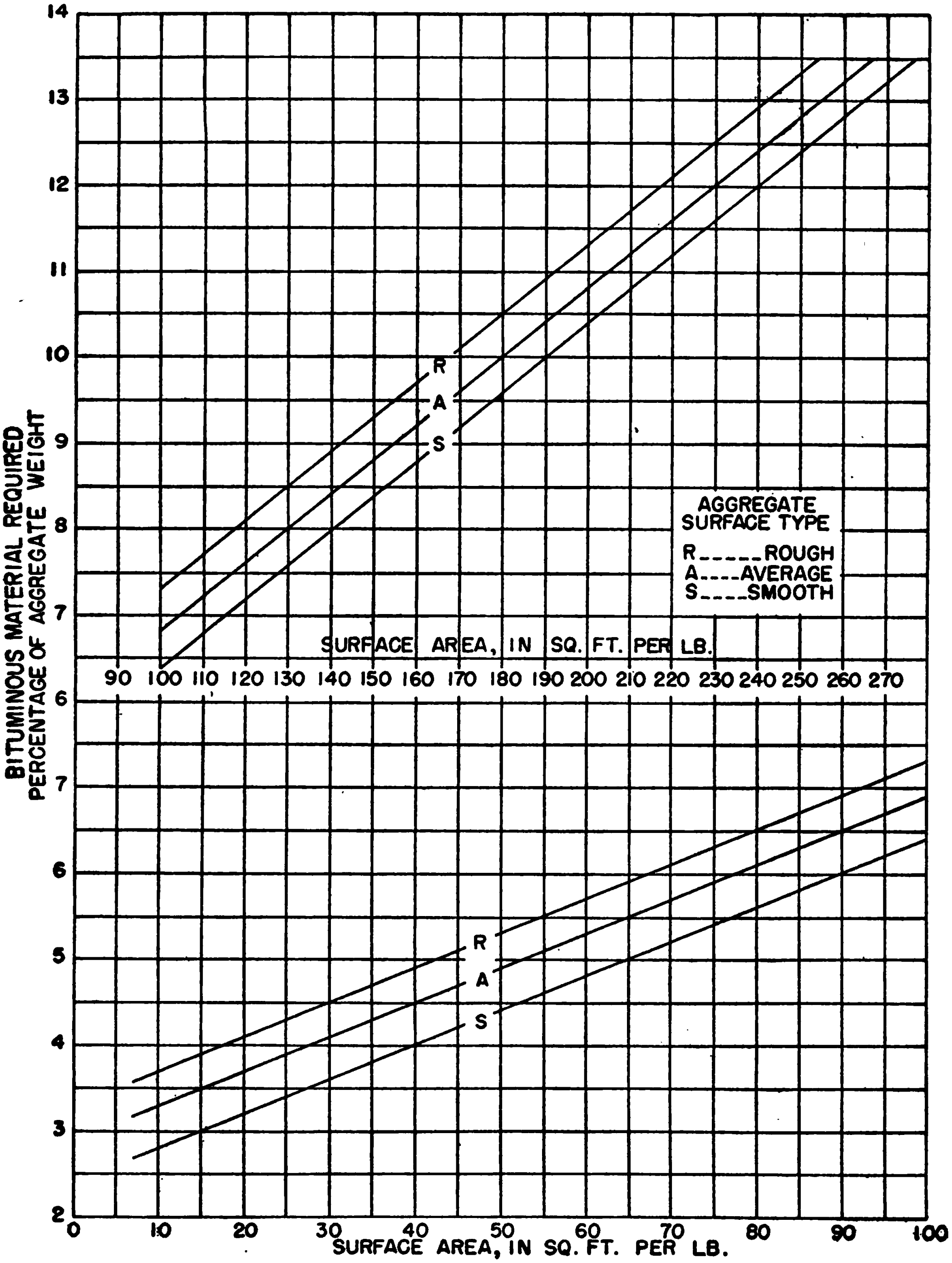
(1) Percentage of bitumen for aggregate gradations shown in table XXIV ordinarily varies between 3.5 and 7.0 percent.

(2) Quantity of bitumen per square yard per inch of compacted thickness for surface course mixtures is about 0.5 gallon.

(3) Quantity of bitumen per linear foot of windrow per square foot of windrow cross section is about 0.5 gallon.

b. Aggregate-bitumen relationship.—Amount of bitumen required by an aggregate depends upon the surface area of the particle composing the aggregate. There should be enough bitumen in a mix to coat each particle of aggregate with a thin film of bitumen. Knowing the sieve analysis of an aggregate it is possible to compute its surface area and thus determine the amount of bitumen necessary to coat the particles. The character of the surface of aggregate particles also has an influence on the amount of bitumen required. Two aggregates with the same sieve analysis, one composed principally of smooth gravel and sand, and the other composed principally of rough crushed rock particles, will require different amounts of bitumen, the latter aggregate demanding the greater amount.

c. Bitumen determination curves.—The series of curves shown in figure 116 presents a method of bitumen determination that is adequate for military conditions. A set of sieves and a weight scale are required in connection with field use of the curves. Figure 116 permits the assignment of a factor to compensate for type of surface of aggregate particles between very rough and very smooth; R, A, and S curves are used respectively for rough, average, and smooth surfaced aggregate particles. In general the A curve is used, but the R curve might apply to such material as soft crushed limestone, and the S curve to hard, smooth, well rounded pebbles.



NOTES:

CHART APPLIES TO MIXED-IN-PLACE AND PLANT-MIX BITUMINOUS CONSTRUCTION, IT DOES NOT APPLY TO BITUMINOUS PENETRATION MACADAM CONSTRUCTION

FIGURE 116.—Chart to determine amount of bituminous material required by mineral aggregate based on surface area of aggregate.

d. Surface area determination.—The first requirement in the use of figure 116 is the determination of the total surface area in square feet contained in 1 pound of a given aggregate. This is obtained from a sieve analysis (par. 40, app. III) of a representative sample of the aggregate. The amount of each size of aggregate is expressed as a percentage of the total sample. Multiply the weight percentage of each size by the surface area constant for that size from table XXV. Add the results and the total is the surface area of the entire sample in square feet per pound.

e. Bitumen determination example by figure 116.—This example assumes an average pit run gravel and sand aggregate. Constants from table XXV are applied to the sieve analysis to determine surface area as follows:

Determination of surface area

Sieve analysis	Surface area constant	Surface area
50% passing ¾-inch and retained on No. 10	0. 50 × 4	2. 00
35% passing No. 10 and retained on No. 40	0. 35 × 18	6. 30
12% passing No. 40 and retained on No. 200	0. 12 × 80	9. 60
3% passing No. 200	0. 03 × 250	7. 50
Total	100%	25.40 sq. ft. per lb.

TABLE XXV.—*Surface area by sieve analysis*

Sieve passing	Sieve retained on	Surface area constant—C	Sieve passing	Sieve retained on	Surface area Constant—C
	¾ inch	3	No. 40	No. 200	80
¾ inch	No. 10	4	No. 200		250
No. 10	No. 40	18			

From the foregoing it is found that the surface area of the aggregate in this case is 25.40 square feet per pound of aggregate (see fig. 116). Along the bottom of the figure on the line "surface area" locate 25.4 and follow the 25.4 line upward to its intersection with curve A, which curve represents an aggregate of average roughness. From the point where the 25.4 line intersects curve A go horizontally to the left-hand margin of the chart to the line "percentage of aggregate weight" and there read the percentage found. In this case it is 3.9 percent, representing the amount of bituminous material that should be added to a given weight of aggregate. For example, in this case 3.9 pounds of bitumen would be added to 100 pounds of aggregate giving 103.9 pounds of mixture. (If emulsified asphalt is used, this quantity must be increased 40 percent to allow for the water in the emulsion, that is, 3.9×1.40=5.5 percent.)

f. Field adjustments.—The calculated percentage of bituminous material will serve as a guide at the start of construction, but field adjustments will be required to secure best results. The calculated percentage of bitumen must not be followed blindly. Change in proportion of added bituminous material will be required whenever the gradation of aggregate changes for the reason that a change in gradation means a change in surface area.

119. Technical control.—Technical control and laboratory assistance during surface course construction are vital to good results. Technical advice is especially required in proportioning bituminous mixtures and in making necessary adjustments of proportions during the progress of construction.

120. Operations in bituminous surface course construction.—*a. Base preparation.*—(1) *Soft areas.*—Repair of soft, spongy areas must be complete. If a bituminous surface course is constructed over a faulty base, the failure will quickly come through the surface. If the weakness is due to faulty subgrade under the base, or if it is due to seepage under the subgrade, repairs must correct the faulty condition by removing the area of base affected, providing any special drainage required, and then removing and replacing as much of the subgrade as necessary. *Under no circumstances should a layer or covering of plastic or cohesive soil be permitted on top of a base course that is to be covered with a bituminous surface course.* Such layers always result in a failure of the surface course.

(2) *Tightly bonded bases.*—Soft spots and holes or depressions in the base course are repaired. All loose and defective material is removed, replaced, and compacted with high quality granular base material or with bituminous premix patching material (par. 126*f*). After all base repairs are made, the entire area to be covered with a bituminous surface course is cleaned by rotary sweeper to remove dust, dirt, and all loose foreign material preparatory to applying bituminous primer.

(3) *Loosely bonded bases.*—Before priming loosely bound bases they are lightly bladed to correct grade, sprinkled with water as needed, and rolled.

b. Applying bituminous material by distributor (fig. 117).—(1) *Equipment and temperature control.*—(*a*) The principal method of applying bitumen is by pressure distributor, although hand spraying may be used. In order to prevent overlapping at the end junction of two applications, the distributor should be promptly shut off and, if necessary to prevent dripping, a drip pan should be inserted under the nozzles when the application begins to thin just before the tank is emptied. Before application of a new load of bitumen, a strip of building paper may be spread over the treated surface so that the sprayers are operating at full force when the uncovered surface is reached. Hand spraying is employed to touch up all areas unavoidably missed by the distributor.

(*b*) For best results no distributor application of bitumen should be made when the air temperature in the shade is below 45° F.

(*c*) Practically all bituminous materials are heated for distributor application. They may be heated in storage tanks, in railroad tank cars, in the 1,500-gallon tank trailer with steam coils, or in the distributor itself. Application or spraying temperatures are given in table XXXVI. Precautions against fire and explosions must be enforced when handling heated tar or asphalt cut-backs (RTCB, RC, MC products).

(2) *Controlling rate of application of bitumen.*—(*a*) When distribution of bituminous material is specified in terms of gallons per square yard as in surface treatment, seal coat and penetration construction, table XL is used to determine distance to be covered by a distributor load. For example, to spread a distributor load of 1,250 gallons at 0.25 gallon per square yard over a width of 10 feet the length of spread from table XL is $(1{,}080+45)=1{,}125$ feet at the rate of 1.0 gallon per square yard. At 0.25 gallon per square yard the length of spread is $\frac{1{,}125}{0.25}=4{,}500$ feet. The tachometer device on the distributor operated by the cycle-type wheel shown in figure 117 is used to control the required spread. Table XLIII may be used for determining quantity of bitumen in a partly filled tank or distributor.

(*b*) When bitumen distribution is specified in terms of percentage (p) by weight of aggregate, as in adding bitumen to aggregate to be mixed in place, it is first necessary to find the cross sectional area (A) of the windrow as illustrated in table LVI. Next determine the dry loose unit weight (W_L) of a representative sample (par. 36, app. III) of the aggregate. To determine (W_L) use a box or pail having a volume from ½ to 1 cubic foot. Accurately determine its level full volume (V) by measurement or by liquid. Fill the container level full with a representative sample of the dry loose aggregate and weigh the contents (w). Loose unit weight of aggregate is:

$$W_L=\frac{w}{V}\text{(pounds per cubic feet)}$$

Compacted unit weight (Wc) will be about 1.25 times W_L. The weight of bitumen (Bw) to be added per lineal foot of windrow then is:

$$Bw=p\times A\times W_L$$

The volume of bitumen (Bv) per linear foot of windrow is obtained by dividing Bw by the weight per gallon of the bitumen (U) obtained from table XXXIX.

$$Bv=\frac{Bw}{U}=\frac{p\times A\times W_L}{U}\text{ (gallons of bitumen per linear foot of windrow)}$$

This quantity of bitumen is generally applied in two or more applications. If Bv works out to be 2.4 gallons per linear foot, the spreading could be made in three applications of 0.8 gallon each. A distributor load of 1,250 gallons would be uniformly spread over $\frac{1,250}{0.8}=1,560$ linear feet of windrow, and three loads would be required to apply the total quantity required. The tachometer device (fig. 117) on the distributor is used to control the desired spread.

(3) *Prime coats.*—The priming operation is very important and must be done carefully and completely. The base to be primed should be reasonably dry and must be free of standing water. Bone dry bases are sometimes not readily penetrated by bituminous material, and it will be helpful to sprinkle them lightly with water and allow it to be absorbed before distributing the prime coat. Best priming results are obtained during the hottest part of the day. Grade of bituminous material also affects amount and rate of penetration. Tables XXXVII and XXXVIII indicate appropriate grades of bituminous primers. Amount of primer to apply must be judged by the ability of the base to absorb it. As much primer should be spread in one application as the base can absorb. Rates of application vary from 0.2 to 0.8 gallon per square yard. Prime coat should be allowed to cure at least 24 hours before starting any additional construction over it.

(4) *Surface treatments and seal coats.*—Each required application of bituminous material is uniformly spread at the prescribed tem-

perature and at the prescribed rate per square yard. If a mineral aggregate cover is to be applied, the aggregate is uniformly spread immediately following the distributor.

(5) *Mixed-in-place construction.*—Bituminous material at the prescribed temperature is spread upon the aggregate in place in two or more equal applications until the required quantity per square yard has been added. Spot applications during mixing are made to correct any deficiencies that appear. If mixing in place is done by traveling mixer, bituminous material is measured and added by this machine, and not by distributor, except for spot applications for adjustments.

(6) *Penetration macadam.*—Each required application of bituminous material is made by distributor at the prescribed temperature and at the prescribed rate per square yard.

c. Placing mineral aggregates.—(1) *General.*—To obtain smooth, uniform surface courses it is essential that the mineral aggregate be placed in a uniform manner, both in respect to rate of spread and nonsegregation of particle sizes. See tables in appendix V for rates of spreading aggregate.

(2) *Quantity.*—As a general rule in bituminous surface treatments, 10 pounds of aggregate are required per square yard for each 0.1 gallon per square yard of bituminous material not counting the prime coat. Tables XLV and XLVI are used to estimate quantity of aggregate per square yard for bituminous mixtures.

(3) *Surface treatment and seal coat aggregate.*—Aggregates must be clean and free from dust. Better results are obtained if they are dry. Spreading of aggregate immediately follows application of bitumen. Aggregate is always spread ahead of truck wheels (fig. 118). This requires backward movement of trucks while spreading. Under no circumstances is traffic permitted over fresh spreads of bitumen. At longitudinal joints mineral aggregate is spread only to within 8 inches of the fresh strip until bituminous material has been applied to the adjoining longitudinal strip.

(4) *Aggregate to be mixed in place.*—When any or all of the aggregate is obtained from the base course, it should be scarified to the required depth and bladed into uniform windrows. The uncovered base may then be primed and after curing, the windrow is bladed onto the primed strips. The remaining base may then be primed. The windrows are then measured and sampled for sieve analysis. Any additional aggregate is then added as needed. When all new material is imported it is dumped into windrows on the primed base. The individual windrows are then dry mixed until uniform in size and particle gradation. Windrows are measured and sampled for sieve analysis to control addition of bitumen.

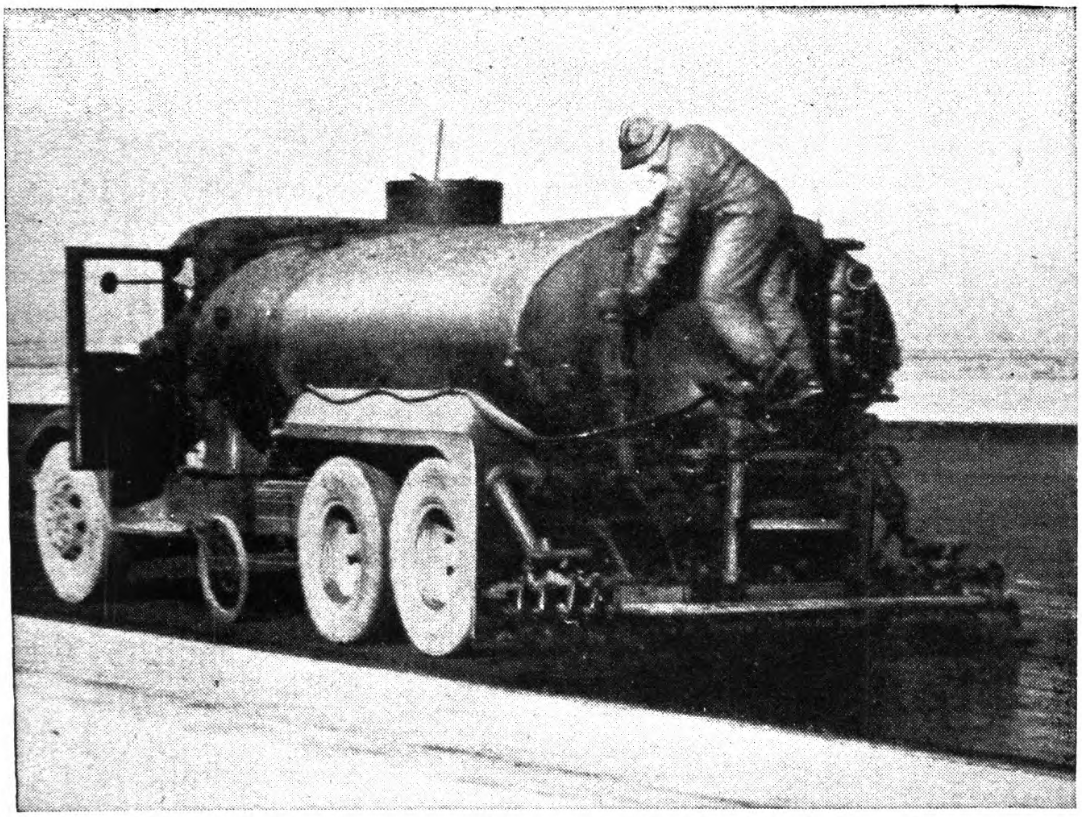


FIGURE 117.—Distributor spreading bituminous material. Illustration shows process. Similar equipment issued to battalion.

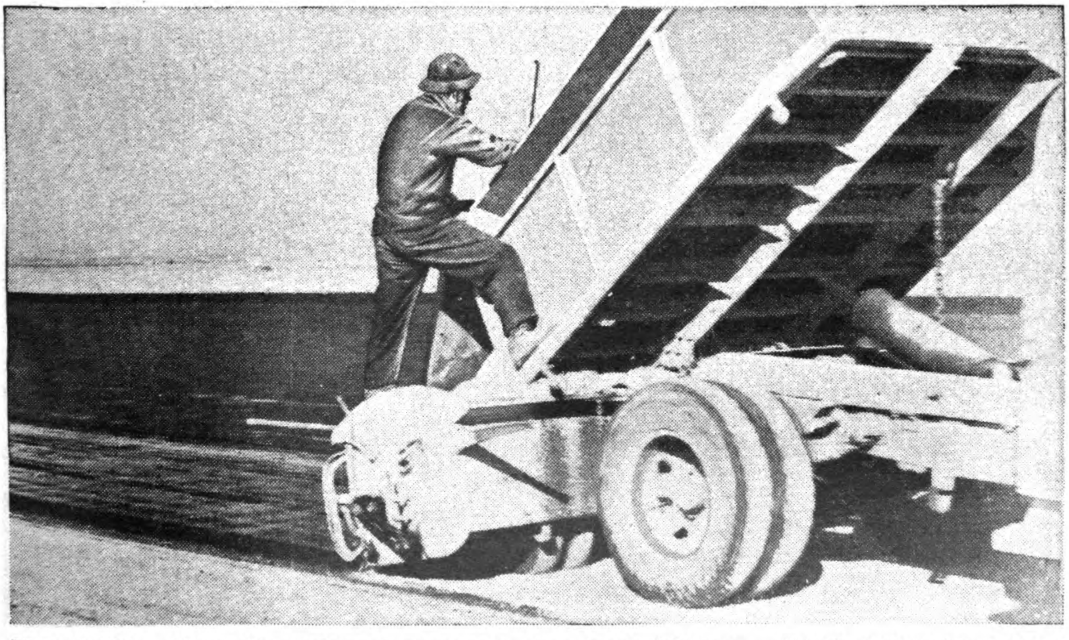


FIGURE 118.—Spreading mineral aggregate over fresh bitumen. Truck moves in reverse while spreading.

(5) *Penetration macadam aggregate.*—Stakes, depth gage blocks, guide ribbons, or side forms may be used to control placing of aggregate. The coarse aggregate is evenly spread without segregation of sizes. If the stone is spread by hand, the loads are dumped outside the area on which it is spread. Fine aggregate (screenings) is always spread over freshly applied bitumen before rolling is resumed.

d. Mixing in place.—(1) The windrows are first flattened and bitumen is added by distributor. A harrow follows the distributor after each application and continues to operate on the treated strip until all free bitumen is mixed into the aggregate. Mixing is then completed by a combination of harrow, cultivator, grader, and rotary tiller until the windrow is a uniform mixture throughout. During the mixing process with grader, the windrow is moved from side to side by successive cuts with the blade. Several graders operate one behind the other on each windrow. If the mixture becomes wet, mixing continues until it has dried. Moisture content should not exceed 2 percent by weight of aggregate except for emulsion mixes. After mixing is complete the material is again bladed into a windrow preparatory to spreading. In the event of rain, less water is absorbed by material in a windrow than is spread out. The completed mix should have all particles coated and should be uniform in color. A desirable mix should "creep" when disturbed. A simple field test is to disturb the windrow slope with the foot and observe the action. If it flows readily the mix is too dry. If it stands vertically it is too rich. If it flows or "creeps" it is about right. A handful squeezed in the palm of the hand will compact and remain in that shape when the hand is opened. A handful rubbed on the palm will leave a brownish stain only when rubbed under pressure.

(2) The traveling mixer (fig. 119) may be used for this work. It progressively mixes each windrow by scooping it up in its forward travel, adding and mixing bitumen, and depositing a mixed windrow or a spread mixture behind it. Cross sectional area of windrows is generally 7 to 10 square feet. Within this range the size of each windrow should be constant throughout its length. If size of windrow is not uniform the amount of bitumen added must be adjusted during travel to keep the proportions of aggregate and bitumen constant.

e. Plant-mixing.—(1) A centrally located plant is necessary for preparing all hot-laid mixtures. A central plant is also especially adapted to situations where all aggregate for the surface course is to be imported. The mixing plant may be set up at the aggregate pit and the completed mixture trucked to the runway. Truck bodies may be given a thin coating of oil to prevent sticking of mixture and to facilitate dumping.

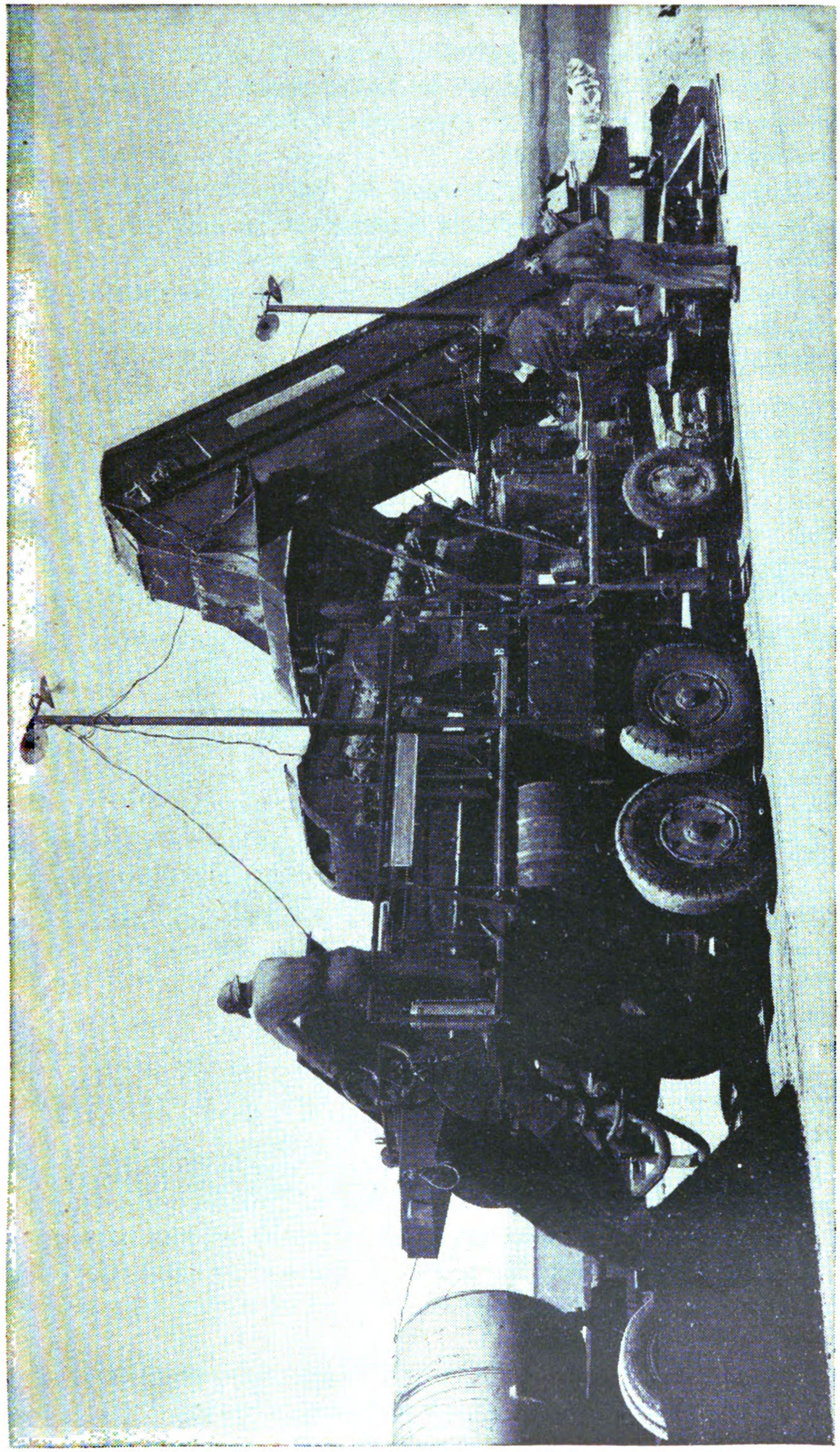


FIGURE 119.—Windrow of aggregate in place on runway being mixed with bitumen by traveling mixer.

(2) Mixing plants are of two general types: the continuous aggregate feed type similar to the traveling mixer and the batch type. In military operations the continuous feed type is generally used. For detailed information on batch-type plants reference is made to standard texts in the unit library.

(3) Properly graded aggregate must be fed to the plant. If the gradation cannot be kept reasonably constant, the proportion of bitumen added must be adjusted with changes in gradation.

(4) Hot mixing using cut-back asphalt or tar requires extreme care to avoid fires and explosions. Only tanks with closed steam coils should be employed for heating.

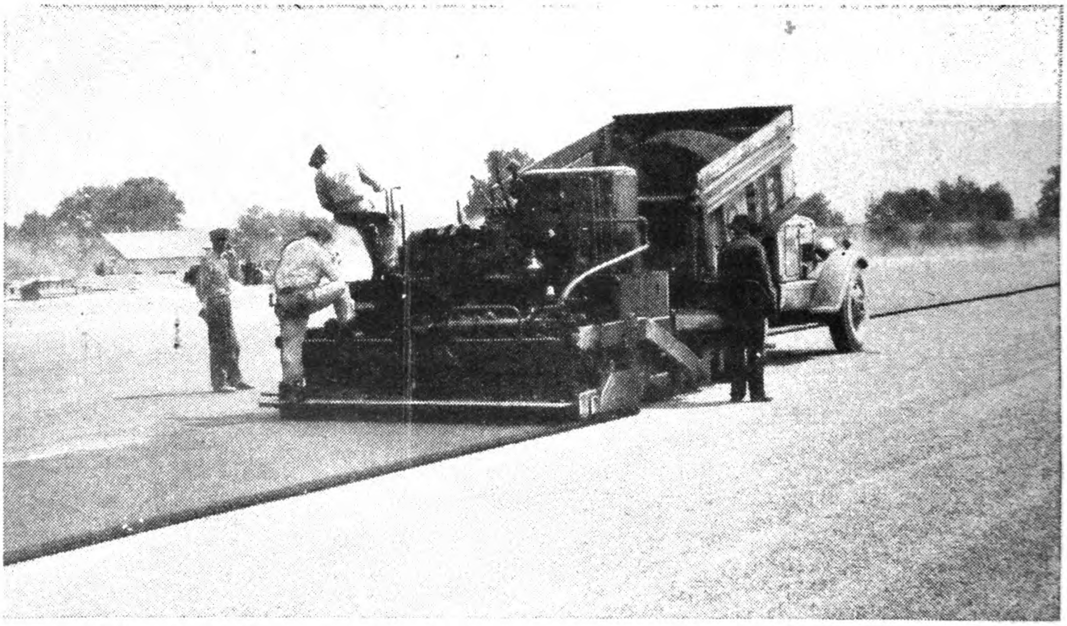


FIGURE 120.—Spreading and finishing machine laying bituminous surface course. Mixture prepared at central plant and delivered by truck.

(5) Aggregate must not be overheated. The usual range of temperature is 225° to 350° F. as the aggregate leaves the drier. Wet aggregate is automatically dried when it is heated; but if wet aggregate is to be mixed cold it must be cooled after drying.

f. Spreading mixtures.—(1) *Hot-laid mixtures.*—If a spreading and finishing machine (fig. 120) is used, the hot mix is dumped from the truck directly into the spreader. Otherwise the hot mix is roughly spread by end dumping from the truck and finished by hand shoveling and raking. An improvised drag constructed of timber may also be used.

(2) *Cold-laid mixtures.*—Cold-laid mixture may be spread and finished by a spreading and finishing machine, or spread from wind-

rows by grader. Spreading from a windrow is done in increments to obtain a surface of correct, uniform thickness. A highly skilled grader operator is required for good results.

g. Compaction.—Rolling proceeds in a longitudinal direction, beginning at the outer edges of each strip and working toward the center, each trip overlapping the prior trip by about one-half the width of the rear roll. If the mixture tends to stick to roller wheels, they are moistened with water or light oil.

(1) *Compacting surface treatments and seal coats.*—Immediately after spreading mineral aggregate cover the surface is smoothed by grader, sweeper, or drag to distribute material uniformly. The layer is then rolled with the 10-ton three-wheel or two-axle tandem roller. Overrolling or use of too heavy a roller may cause excessive crushing of aggregate, which is to be avoided. The rubber-tired roller is also effective for this work. Successive rolling and sweeping proceeds rapidly, care being taken not to disturb particles already bound in place. After a few days all loose aggregate is finally swept into piles and removed from the runway into stockpiles.

(2) *Compacting cold-laid mixture.*—(*a*) *Macadam aggregate.*—Three-wheel 10-ton rollers are used to compact macadam aggregate mixtures.

(*b*) *Graded aggregate.*—Initial rolling is done with the rubber-tired roller (fig. 121) and finish rolling is done with the two-axle tandem roller. Intermittent rolling over several days or several weeks if weather permits may be necessary to get the required density and stability in the surface course.

(3) *Compacting hot-laid mixtures.*—These must be compacted while they are hot. Initial rolling is done with the 10-ton, three-wheel roller. Final rolling consists of longitudinal, diagonal, and cross-rolling with a two-axle tandem roller or longitudinal rolling with the three-axle tandem roller.

h. Joints.—Longitudinal and transverse joints require special attention to insure a good junction. In hot-laid construction the old work is hand trimmed before new work is started. Hand work is necessary to patch and seal these joints where they are imperfect.

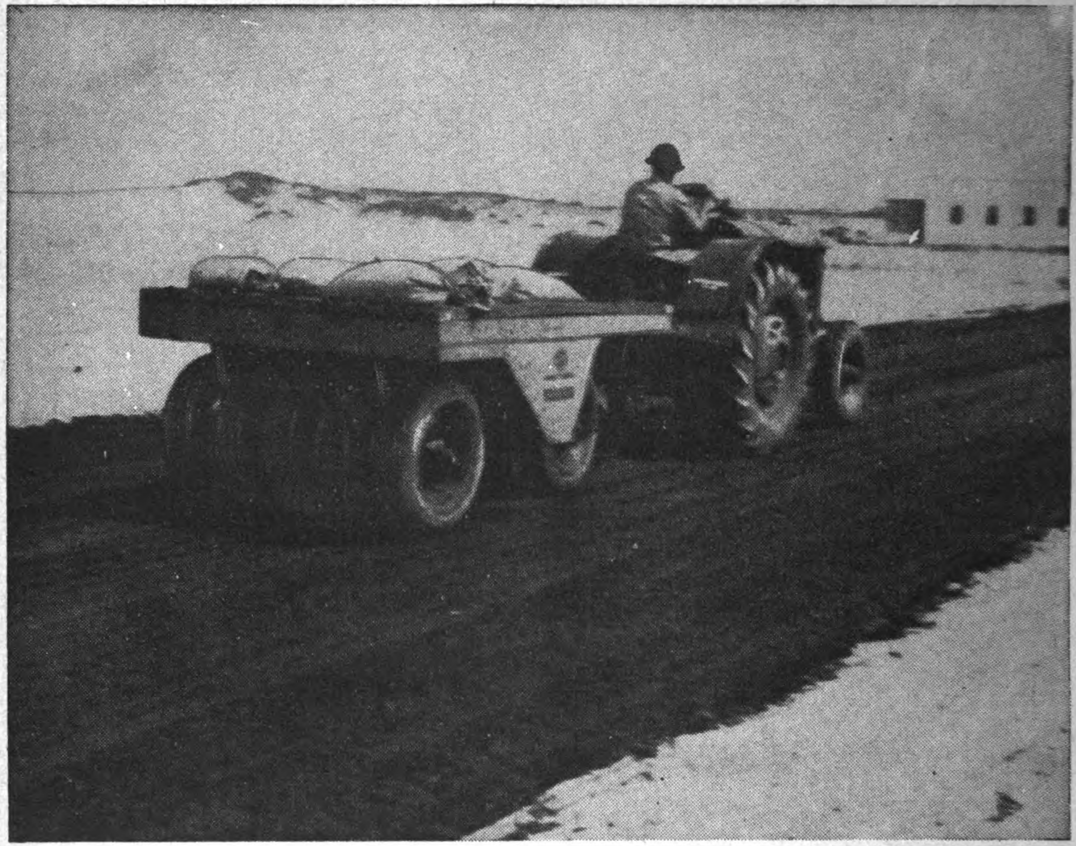


FIGURE 121.—Initial compaction of mixed-in-place surface with rubber-tired roller.

SECTION II

DETAILED CONSTRUCTION PROCEDURES

	Paragraph
Stabilized soil surface course	121
Bituminous surface courses	122
Concrete slabs	123

121. Stabilized soil surface course.—*a. Description.*—This is a mechanically stabilized type of surface course using a mixture of selected local materials. It may be constructed to any thickness in layers 3 to 6 inches thick. Recommended minimum thickness for this surface course is 4 inches.

b. Materials and construction procedure.—Materials requirements are the same as given in paragraph 92*b*, except that only gradings B and C, table XIII, are used and the plasticity index of the fraction passing No. 40 should be not less than 3 nor more than 6. Construction methods are the same as for stabilized soil base course (par. 92). Calcium chloride is not used as a stabilizer in this type of surface on airdromes because of possible corrosion of airplanes.

122. Bituminous surface courses.—*a. Prime coat and dust palliative* (par. 116*f*).—Every base should be primed and cured before a bituminous surface course is constructed upon it. See paragraph 120*b*(3) for construction procedure. See tables XXXVII and XXXVIII for selection of appropriate bituminous material.

b. Bituminous surface treatment on tightly bound base.—(1) *Procedure.*—Steps in this treatment are as follows:

(*a*) Base preparation (see par. 120*a*).

(*b*) Prime coat (see *a* above).

(*c*) Upon the cured prime coat apply RC-3 at 0.25 to 0.40 gallon per square yard (see par. 120*b*).

(*d*) Cover immediately with aggregate No. IV, table XXIII, at 25 to 40 pounds per square yard (see par. 120*c*).

(*e*) Rolling and finishing (see par. 120*g*).

(*f*) Seal coat (see *d* below).

(2) *Alternates and variations.*—Other bituminous materials may be substituted for RC-3 (see tables XXXVII and XXXVIII). When heavier surface treatments are desired, aggregate No. III, table XXIII, may be used or steps 3, 4, and 5 of the above treatment may be repeated before doing step 6. This gives a double surface treatment.

c. Bituminous surface treatment on loosely bound base.—(1) *Procedure.*—Steps in this treatment are as follows:

(*a*) Base preparation (see par. 120*a*).

(*b*) As a primer and binder apply MC-2 at 0.5 to 0.8 gallon per square yard (see par. 120*b*(3)). For alternate materials see tables XXXVII and XXXVIII.

(*c*) Cover immediately with aggregate No. IV, table XXIII, at 25 to 40 pounds per square yard (see par. 120*c*).

(*d*) Apply MC-2 at 0.25 to 0.40 gallon per square yard as above.

(*e*) Lightly blade or drag the surface until all aggregate particles are thoroughly coated.

(*f*) Rolling and finishing (see par. 120*g*).

(*g*) Seal coat (see *d* below).

(2) *Alternates and variations.*—Where sufficient suitable loose aggregate exists on the runway it may be bladed into windrows then bladed onto the first application of bitumen in place of new aggregate. For other bituminous materials which may be used see tables XXXVII and XXXVIII.

d. Seal coat.—(1) *Procedure.*—Steps in this treatment are as follows:

(*a*) Clean the surface to be sealed with the rotary sweeper.

(*b*) Apply RC-2 at 0.15 or 0.25 gallon per square yard (see par. 120*b*).

(*c*) If a mineral cover is required on the seal coat, aggregate No. VI (or No. V), table XXIII, is immediately spread at 15 to 25 pounds per square yard. Other cover material may be used for camouflage purposes (see ch. 14).

(*d*) Rolling and finishing (see par. 120*g*).

(2) *Alternates and variations.*—Other bituminous materials may be substituted for RC-2 (see tables XXXVII and XXXVIII).

e. Mixed-in-place surface course using graded aggregate.—This type of surface course has wide use because it may employ a variety of natural aggregate and several grades of bitumen. It is particularly adapted to the use of graded gravel and sand. It is quickly constructed with battalion equipment, though construction is delayed by wet or cold weather. It is not less than 2 inches nor more than 4 inches thick. It is generally regarded as of intermediate quality from the standpoints of service and durability. Maintenance facilities are necessary.

(1) *Procedure.*—Steps in this treatment are as follows:

(*a*) Base preparation (see par. 120*a*).

(*b*) Prime coat (see *a* above).

(*c*) Mineral aggregate meeting one of the designations in table XXIV is prepared (see par. 120*c*).

(*d*) Proportion of bituminous material to be added is determined (see par. 118).

(*e*) MC-3 is applied by distributor (see par. 120*b*).

(*f*) Mixing (see par. 120*d*).

(*g*) Spreading (see par. 120*f*).

(*h*) Compacting (see par. 120*g*).

(*i*) Seal coat using MC-3 (see *d* above). Application of seal coat may be delayed for a period of time, if weather permits, to allow the surface course to cure and to allow for additional rolling.

(2) *Alternates and variations.*—For cool weather work MC-2 is recommended unless a traveling mixer is used, and in hot weather MC-4 may be used. For other bituminous materials see tables XXXVII and XXXVIII.

f. Mixed-in-place surface course using macadam aggregate.—This type of surface course is constructed not less than 2 inches nor more than 3 inches thick. It has the same characteristics as the mixed-in-place surface course using graded aggregate (*e* above) except that aggregate requirements are more strict.

(1) *Procedure.*—Steps in this treatment are as follows:

(*a*) Base preparation (see par. 120*a*).

(*b*) Prime coat (see *a* above).

(*c*) A layer of aggregate, No. II, table XXIII, is spread upon the primed base (see par. 120*c*).

(*d*) RC-3 is applied by distributor in two equal spreads with mixing between applications (see par. 120*b*). Each application will generally be 0.3 to 0.5 gallon per square yard.

(*e*) Mixing (see par. 120*d*).

(*f*) Spreading (see par. 120*f*).

(*g*) Compacting (see par. 120*g*).

(*h*) Seal coat (see *d* above).

(2) *Alternates and variations.*—For other bituminous material see tables XXXVII and XXXVIII.

g. Bituminous penetration macadam surface course (see par. 98).—This type of surface course is constructed about 2½ inches thick. It is a good quality surface, but rate of construction is slower than mixed-in-place work. Construction is delayed by wet or cold weather. Aggregate must consist of angular particles. Crushing and screening equipment is required.

(1) *Procedure.*—Steps in this treatment are as follows:

(*a*) Base preparation (see par. 120*a*).

(*b*) Prime coat (see *a* above).

(*c*) Coarse angular aggregate, No. I, table XXIII, is spread to a loose depth of about 3½ inches (see par. 120*c*) and compacted (see par. 98*c*).

(*d*) Hot bitumen is applied in one application by distributor (see par. 120*b*). Rate of spread varies from 1.9 to 2.1 gallons per square yard.

(*e*) Aggregate screenings, No. IV, table XXIII, are spread and rolled with 10-ton roller with necessary additions of screenings until the surface is keyed and dense.

(*f*) The surface is swept clean of all loose material and another application of the same bituminous material is spread at 0.3 to 0.5 gallon per square yard. While the bitumen is still warm, screenings are spread, rolled and broomed as before. No loose particles are allowed to remain on the finished surface.

(2) *Alternates and variations.*—For selection of other bituminous materials see tables XXXVII and XXXVIII.

h. Plant-mix surface course, cold-laid or hot-laid.—(1) This type of surface course is constructed not less than 2 nor more than 4 inches thick. It may be constructed in two layers of 2 inches each. A variety of graded aggregate can be used, but angular coarse aggregate is preferred. Fine aggregate may be crushed particles or natural sand. Dust passing No. 200 sieve may be rock dust, selected inorganic soil, portland cement, or hydrated lime. Plant mixing permits good control of proportioning and uniform mixing, hence good quality surfaces. Hot plant-mix is the highest type of bituminous construction and produces stable, serviceable, durable surfaces that require little maintenance.

(2) *Procedure.*—Steps in this treatment are as follows:

(*a*) Base preparation (see par. 120*a*).

(*b*) Prime coat (see *a* above).

(*c*) Preparation of plant mix. Bituminous material is selected from table XXXVII. Aggregate must meet one of the designations in table XXIV. Plant operation is covered in paragraph 120*e*.

(*d*) Placing mixture (see par. 120*f*).

(*e*) Compaction (see par. 120*g*).

(*f*) Seal coat (see *d* above).

123. Concrete slabs.—*a. Materials.*—(1) *Cement.*—Standard portland cement is generally used, although high early strength cement may be used if available (see par. 115*c*). The procedure with high early strength cement is the same as with ordinary cement. In 3 days of curing it attains a strength about 75 percent of the strength at 28 days of standard portland cement. High early strength concrete is especially useful in paving the last strips on a runway so that use of the runway is not delayed by curing the last sections placed.

(2) *Aggregates.*—Requirements for gradation and quality of aggregate are given in paragraph 117*a*. Maximum size of gravel should be about 2 inches.

(3) *Water.*—Water for concrete must be free from oil, acids, alkali and organic matter. In general any water that is fit for human consumption is suitable for concrete. Sea water is not used for concrete in runways.

b. Forms.—Runways are paved in longitudinal strips 20 to 25 feet wide. Side forms are required. These must be securely set true to line and grade and well ahead of concrete placement.

c. Subgrade preparation.—Subgrade preparation includes fine grading, compaction by rolling, and sprinkling. This is done just ahead of paving operations. A subgrade template which slides on the side forms is used to test and to control accuracy of operations. If the subgrade is dry it will absorb moisture from the wet concrete. This is prevented by wetting the subgrade. Light sprinkling just ahead of the concrete is of some value. Thorough wetting the night before is best. On subgrade soils such as loess, clay, gumbo, adobe, and expansive or frost-action silts a covering is desirable to separate the slab from the soil. A subgrade blanket course of sand (par. 63*c*) is generally effective except on loess soil. Thickness of this layer varies from 2 inches to 6 inches. A 6-inch blanket is used on very bad soils and especially over frost-action silts. (See par. 43, app. III.) Loess subgrade should have a covering of bitumen-saturated paper.

d. Preparation of aggregates.—Concrete aggregates are generally prepared by screening into at least two sizes, coarse and fine. Washing to remove excess dirt is sometimes necessary in connection with screening.

e. Proportions.—(1) *Water-cement ratio.*—The ratio of water to cement in concrete for runways should be not more than 6 gallons of water per bag (94 lb.) of cement. In computing the water content of concrete all moisture carried by the aggregate (and any admixture) is included in applying this rule. In other words, total water, including that carried (see table LIX) by the aggregate, by calcium chloride solution if used, and that added to the mixture, must not exceed 6 gallons per bag.

(2) *Cement content.*—Cement content of concrete on runways should be about 5 bags of cement (470 lb.) per cubic yard of finished concrete. However, this factor may vary from 4½ to 6 bags per cubic yard depending upon quality of cement and aggregate available, working conditions, and quality of concrete desired.

(3) *Aggregate.*—Proportions of fine and coarse aggregate are adjusted to give a workable, relatively dry plastic mix having a slump (par. 50*d*, app. III) less than 2 inches if to be consolidated by mechanical vibrators. A slump of 3 inches is permissible for hand tamping and spading. Average proportions of fine and coarse aggregate are 40 percent of fine aggregate (sand) and 60 percent of coarse aggregate (gravel). (See tables LX and LXI.)

f. Batching.—Aggregates are combined in desired proportions at the batching plant either by volume or weight measurement. Size of batch is governed by the capacity of the mixer (paver) being used. A crawler-mounted 34 E paver is provided in the heavy construction set. Batches are transported to the mixer on the runway by truck. If large trucks capable of carrying more than one batch are used, the bodies are subdivided by bulkheads to form compartments for individual batches. Cement may be added at the batching plant, at the paver, or at an intermediate point.

g. Mixing.—Mixing is done on the runway by the crawler-mounted mixer. Water (and admixture if used) is added at the mixer. Time of mixing must be not less than 1 minute after all materials are in the mixer drum. Mixing time should not exceed 2 minutes.

h. Placing.—After a batch is mixed, it is deposited as nearly as possible in its final position on the runway.

i. Finishing.—(1) Finishing operations include consolidating the plastic concrete, spreading and leveling it by screeding the surface of the slab true to line and grade, floating and straightedging, belting or brooming to roughen the surface, and joint trimming. Finishing operations follow the paver as closely as possible. Belting or brooming is not done until the water sheen has disappeared from the fresh concrete.

(2) Machine finishing is preferred, but operations can be done by hand. If finished by hand careful attention to spading and consolidating is required. Internal vibrators may be used in consolidating operations.

(3) A rough "sandpaper finish" is desired. The surface should not vary more than ⅛ inch from a 10-foot straightedge laid in any direction. Steel troweling is not used. Overworking the surface is especially to be avoided.

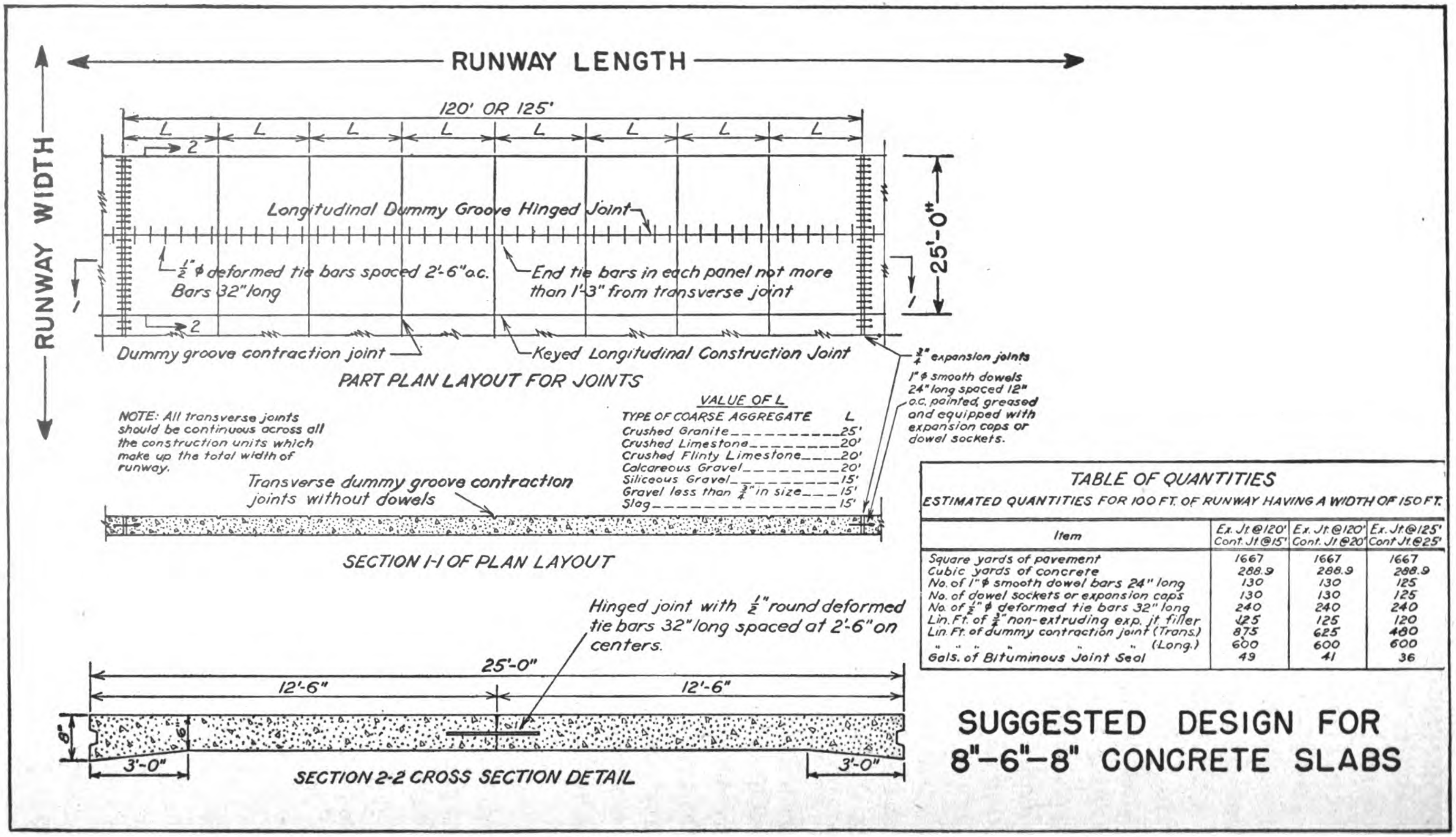
j. Curing.—(1) Freshly finished concrete slabs must be protected against loss of moisture by evaporation, so that the chemical reaction between water and cement necessary for development of strength will not be interrupted nor retarded. More than enough water is used in mixing concrete to satisfy the chemical requirements of the cement. Curing procedure must keep this water in the slab until strength has been attained. Curing should be as thorough as the military situation permits.

(2) After finishing, as soon as the slab has sufficiently hardened it is prepared for curing by any standard method: ponding with water, covering with paper; covering with sand or straw kept damp by sprinkling; or covering with a sprayed curing material such as emulsified asphalt, cut-back tar, or cut-back asphalt. Curing must be continuous. Intermittent sprinkling is not acceptable. Normal curing period for standard portland cement concrete is 7 to 14 days at temperatures above 50° F., and 14 to 21 days if air temperature is below 50° F. Curing period for high early strength concrete and for standard portland cement concrete with an admixture of calcium chloride is 2 to 7 days depending upon prevailing temperature. Concrete must be protected from freezing during construction and curing.

k. Calcium chloride admixture.—The rate of hardening of cement may be increased by using an admixture of calcium chloride ($CaCl_2$). Use of this chemical is not recommended as standard procedure, but it is an expedient that may be useful in some situations. When so used, the material in flake form may be added to the mix in either dry or solution form. When used in dry form, from 1 to 2 pounds per bag (94 lb.) of cement are placed in the aggregate, *but not in contact with the cement*, just before materials are dropped into the mixer drum. Where used in solution form from 1 to 2 quarts per bag (94 lb.) of cement are introduced into the mixer drum with the mixing water. The solution is prepared by dissolving and thoroughly stirring 1 bag (100 lb.) of calcium chloride in enough water to make 25 gallons (100 qt.) of solution. Exact amount of calcium chloride used depends upon prevailing temperature. Recommended amounts are 2 pounds dry or 2 quarts solution for working temperatures below 80° F.; 1.5 pounds dry or 1.5 quarts solution for temperatures between 80° and 90° F.; and 1 pound dry or 1 quart solution for temperatures above 90° F.

l. Joints.—Several types of joints are necessary in concrete runways. Principal types are expansion joints, longitudinal and transverse dummy groove joints, hinged joints, keyed joints and construction joints. For details see figures 122 and 123.

m. Order of paving in strips.—Runways are paved in longitudinal strips. To allow for shrinkage, alternate strips (fig. 124) are paved and allowed to harden before paving the strip between. It is advisable to lay out the work so that the last sections paved are along one edge so as not to prevent emergency use of the rest of the runway. By placing concrete in the vital areas first, sufficient curing time to develop slab strength for emergency use will elapse while the last strips are being placed.


RUNWAY LENGTH
RUNWAY WIDTH
120' OR 125'
L
2
1
25'-0"
Longitudinal Dummy Groove Hinged Joint
$\frac{1}{2}$" ϕ deformed tie bars spaced 2'-6" o.c. Bars 32" long
End tie bars in each panel not more than 1'-3" from transverse joint
Dummy groove contraction joint
Keyed Longitudinal Construction Joint
PART PLAN LAYOUT FOR JOINTS
$\frac{3}{4}$" expansion joints
1" ϕ smooth dowels 24" long spaced 12" o.c. painted, greased and equipped with expansion caps or dowel sockets.
NOTE: All transverse joints should be continuous across all the construction units which make up the total width of runway.
Transverse dummy groove contraction joints without dowels
SECTION 1-1 OF PLAN LAYOUT
Hinged joint with $\frac{1}{2}$" round deformed tie bars 32" long spaced at 2'-6" on centers.
25'-0"
12'-6"
12'-6"
8"
6"
3'-0"
3'-0"
SECTION 2-2 CROSS SECTION DETAIL

VALUE OF L

TYPE OF COARSE AGGREGATE	L
Crushed Granite	25'
Crushed Limestone	20'
Crushed Flinty Limestone	20'
Calcareous Gravel	20'
Siliceous Gravel	15'
Gravel less than $\frac{3}{4}$" in size	15'
Slag	15'

TABLE OF QUANTITIES

ESTIMATED QUANTITIES FOR 100 FT. OF RUNWAY HAVING A WIDTH OF 150 FT.

Item	Ex. Jt. @ 120' Cont. Jt. @ 15'	Ex. Jt. @ 120' Cont. Jt. @ 20'	Ex. Jt. @ 125' Cont. Jt. @ 25'
Square yards of pavement	1667	1667	1667
Cubic yards of concrete	288.9	288.9	288.9
No. of 1" ϕ smooth dowel bars 24" long	130	130	125
No. of dowel sockets or expansion caps	130	130	125
No. of $\frac{1}{2}$" ϕ deformed tie bars 32" long	240	240	240
Lin. Ft. of $\frac{3}{4}$" non-extruding exp. jt. filler	125	125	120
Lin. Ft. of dummy contraction joint (Trans.)	875	625	480
" " " " " (Long.)	600	600	600
Gals. of Bituminous Joint Seal	49	41	36

SUGGESTED DESIGN FOR
8"-6"-8" CONCRETE SLABS

FIGURE 122.—Concrete runways.

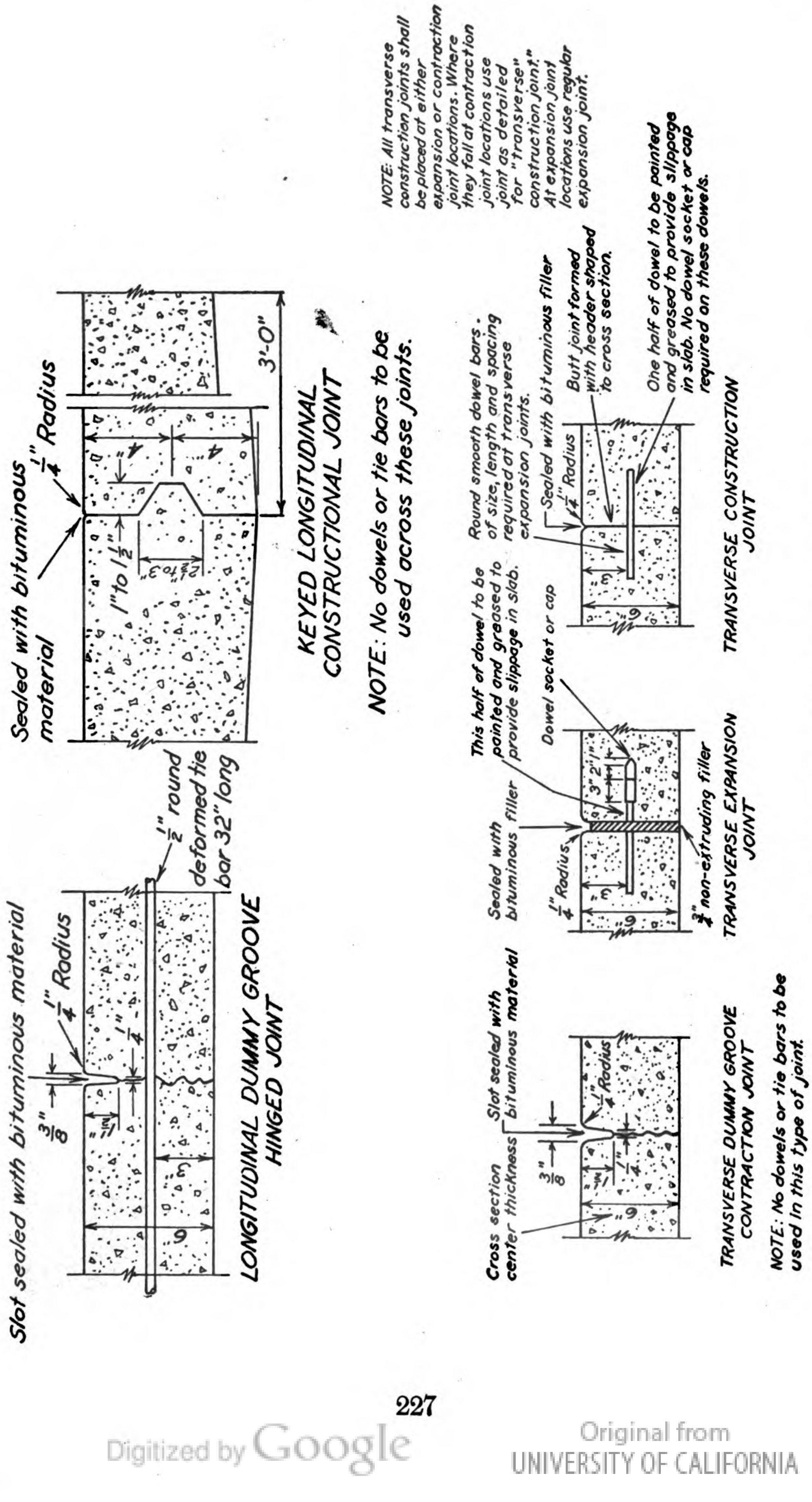

Slot sealed with bituminous material
3/8"
1/4" Radius
1/4"
3"
6"
1/2" round deformed tie bar 32" long
LONGITUDINAL DUMMY GROOVE HINGED JOINT
Sealed with bituminous material
1/4" Radius
1" to 1 1/2"
2 1/2" to 3"
4"
4"
3'-0"
KEYED LONGITUDINAL CONSTRUCTIONAL JOINT
NOTE: No dowels or tie bars to be used across these joints.
NOTE: All transverse construction joints shall be placed at either expansion or contraction joint locations. Where they fall at contraction joint locations use joint as detailed for "transverse" construction joint." At expansion joint locations use regular expansion joint.
Cross section center thickness
3/8"
Slot sealed with bituminous material
1/4" Radius
1/4"
6"
TRANSVERSE DUMMY GROOVE CONTRACTION JOINT
NOTE: No dowels or tie bars to be used in this type of joint.
Sealed with bituminous filler
1/4" Radius
3"
6"
This half of dowel to be painted and greased to provide slippage in slab.
Dowel socket or cap
3"
2"
3/4" non-extruding filler
TRANSVERSE EXPANSION JOINT
Round smooth dowel bars, of size, length and spacing required at transverse expansion joints.
Sealed with bituminous filler
1/4" Radius
Butt joint formed with header shaped to cross section.
One half of dowel to be painted and greased to provide slippage in slab. No dowel socket or cap required on these dowels.
3"
6"
TRANSVERSE CONSTRUCTION JOINT

FIGURE 123.—Joint details for concrete runways.

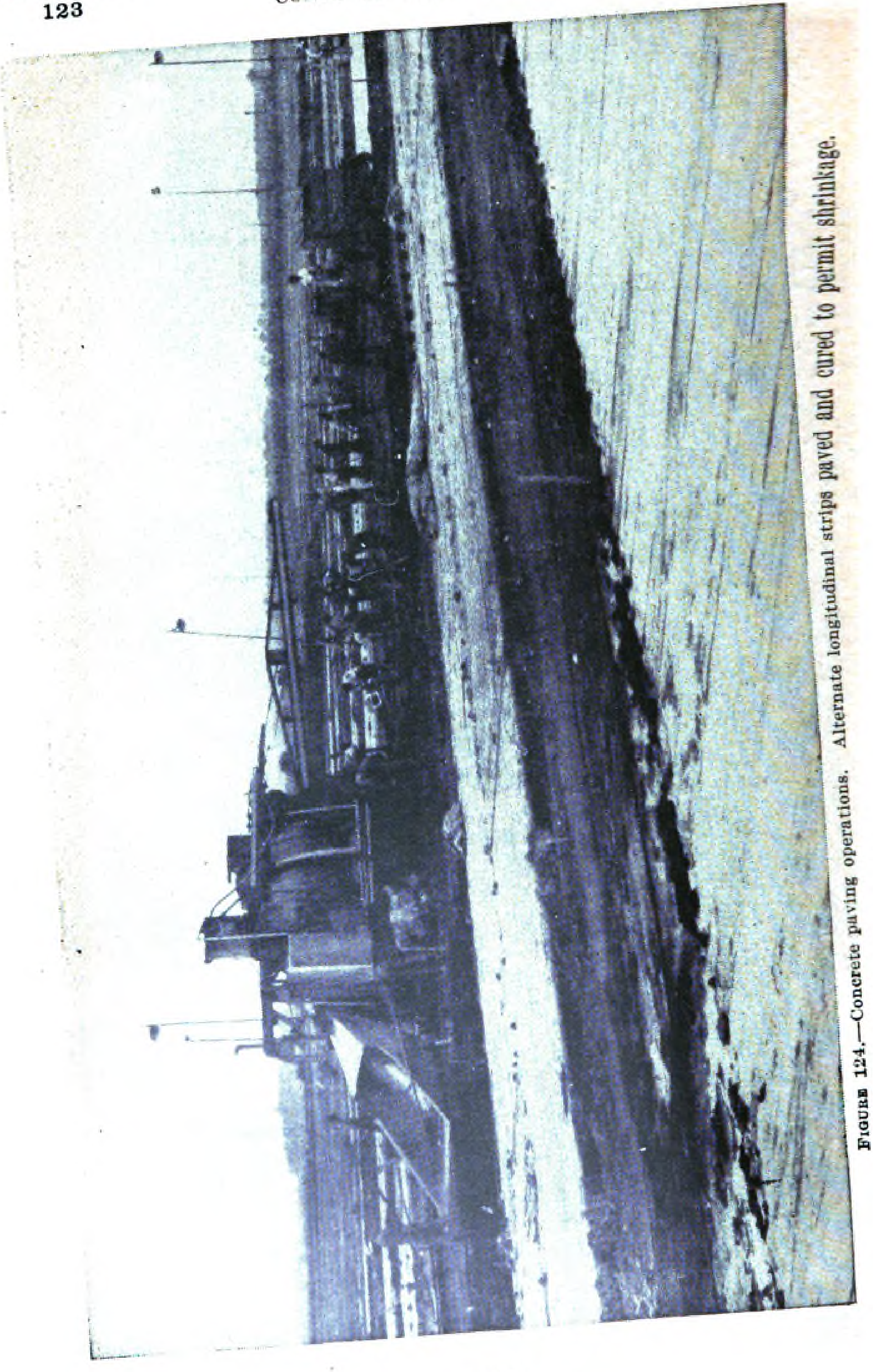


FIGURE 124.—Concrete paving operations. Alternate longitudinal strips paved and cured to permit shrinkage.

CHAPTER 11

AIRDROME MAINTENANCE

Paragraph
Mission 124
Personnel and equipment 125
Routine maintenance 126
Special or emergency maintenance 127
Steel runways 128

124. Mission.—The mission of aviation engineers at field airdromes is to keep the airdromes constantly in condition to serve the aircraft using them. This includes—

(1) Routine maintenance.
(2) Special or emergency maintenance.
(3) Stage construction to improve the airdrome.

125. Personnel and equipment.—A flexible allotment of personnel and equipment with a reserve for special assignment is necessary for maintenance. For example, a company assigned to the maintenance of three airdromes should not be expected to place a platoon at each airdrome. Instead, depending on local conditions, the company commander should place a minimum engineer detachment with equipment at each airdrome, holding the the bulk of his personnel and equipment in a central location prepared to give maximum aid, perhaps after bombardment, where most needed. This central location would most likely be one of the fields where conditions warrant the presence of a larger group. Likewise, the battalion could well retain a portion of the heavy battalion equipment in a central location prepared to reinforce companies as needed.

126. Routine maintenance.—*a. Scope.*—Routine maintenance covers drainage; repairs to runways, taxiways, parking areas, and roads; stockpiling materials for special and emergency maintenance; and snow removal.

b. Inspection and supervision.—(1) Frequent and careful inspection of an airdrome and continuous supervision of repair work are vital requirements in routine maintenance. An engineer officer should carefully inspect all runways periodically to detect early evidence of pavement weakness before actual failure results. These inspections must be especially vigilant during rainy seasons and during spring thaws. Dangerous areas must be marked. Taxiways, parking areas, roads, and other facilities are similarly inspected.

(2) Every defect discovered during inspections must be studied to determine the cause. Pavement defects may result from imperfections in surface construction; they may be caused by concentrated use as in turn-around areas; or they may be the first indications of more deep-seated trouble caused by faulty base or foundation construction or by inadequate drainage. Simple rules for classifying defects cannot be given. Each must be studied as an individual problem to determine the appropriate remedy. It is especially important not to misinterpret first evidences of major defects. Surface patching will not correct a foundation or base course deficiency.

(3) The drainage system at a new airdrome is carefully observed for hydraulic deficiencies during first storms and spring run-off. The system is also inspected after storms for erosion damage and clogged drains.

c. Drainage.—Drainage ditches must be kept constantly clear of weeds, brush, silt, and other accumulations of debris that obstruct flow of water. Erosion damage to ditches is corrected after each storm by backfilling and placing riprap or by lining with compacted bituminous premix. Clean-outs and junction boxes must be periodically cleaned. Clogged drain and culvert pipe must be opened by cleaning. Any deficiencies in the original drainage system lay-out must be corrected as they are discovered. Special attention must be given to drainage maintenance during periods of thaw, especially when accumulations of snow are present. Open side ditches are cleared of snow, and channels are opened through any snow accumulations on the shoulders whenever needed to permit water to escape. Every precaution must be taken to prevent ponding of snow-melt water on the runway, on the shoulders, or in the side channels.

d. Repairs to pavements.—(1) *Soft spots.*—All soft and yielding spots or areas that develop in runway or other pavements must be corrected. Early surface indications of soft spots in base or subgrade under flexible type pavements are often similar to first evidence of defects in the surface course alone, and it is important to differentiate the two. Soft spots may develop slowly at first, but they progress rapidly to failure, with the possibility of serious consequences if not repaired. A section or area of a bituminous surface course that is too rich in bitumen will be displaced in much the same manner as the beginning surface displacement due to soft subgrade or a frost boil. The remedy for an over-rich surface mixture is relatively simple, but the remedy for poor subgrade or base may involved considerable work. Exploratory excavation may be required to determine the nature of the trouble and extent of repair required. If the weakness is due to poor foundation soils or poor foundation compaction, the pavement and defective subgrade are removed. Good granular material such as graded gravel is placed and thoroughly consolidated and the pavement is replaced. If the weakness is due to seepage, it is necessary to install a drain to intercept or remove the water. (See pars. 60 and 61, and app. III.) If the difficulty is due to frost action in the form of frost boils or frost heaves, it is frequently necessary both to replace the frost-action subgrade soil with granular material and to install special drains. Sometimes drainage measures alone will correct frost difficulties, because heaving cannot occur unless there is a water supply during freezing to build up subsurface ice layers or lenses. A critical time for weakness resulting from frost action is in the spring when the ice in the base and subgrade melts and saturates the foundation.

(2) *Surface courses.*—(*a*) Stabilized soil surfaces that are not treated or not primed will require continuous maintenance. This consists of light scarifying or blading with a grader followed by sprinkling and rolling. If small areas of unbound surface start to ravel or to develop ruts or chuck holes, these are patched with stabilized soil mixture following the procedure described below for patching bituminous surface courses. Dust palliatives (except calcium chloride) may be applied to stabilized soil surfaces as part of the maintenance program. Bituminous materials (tables XXXVII and XXXVIII) are useful, but other materials may be employed if conveniently available, such as fluid fuel oil, waste oil, or lignin solution from the pulp and paper industry. Primed surfaces that ravel or rut are likewise patched with stabilized mixture and the patch is primed with bituminous material, using the asphalt kettle hand spray.

(*b*) Bituminous surface courses usually require some maintenance, especially near the ends of runways and taxiways where aircraft do considerable turning. Surface abrasions and wear may be corrected by a bituminous surface treatment. This involves sweeping the work area, spraying with cut-back or emulsified asphalt or with tar, and covering with compacted, clean mineral aggregate (see par. 122*d*). Deeper wear, as in mixed-in-place bituminous surface courses, may require removal of the surface course and replacement with bituminous premix patching material. In this type of patching, edges of the surface course are trimmed vertically after the defective portion of the surface is removed. The outline of the area to be patched is cut in straight lines parallel and perpendicular to the runway centerline. Before placing premix patching material, the vertical edges of the remaining surface course are painted with cut-back or emulsified asphalt to promote bond between the old and new materials. The premix patching material is evenly spread, then compacted to grade by rolling. Waves (wrinkles or shoves) that sometimes develop in mixed-in-place or cold-laid bituminous surfaces may result from insufficient stability in the surface course itself, or from slippage of the surface on the base course. Instability in the surface course may be caused by poor aggregate grading, too much bitumen in the mixture, or insufficient curing and compaction. So long as the displacement is confined to movement in the surface course and does not result from a yielding foundation, the remedy is simple. The defective area may be scarified, reworked, and relaid. Scarifying should not disturb the base. The defective surface may be scarified, removed, and replaced with premix patching material. Waves caused by slipping on the base require removal of the surface and elimination of the slip plane. A frequent cause of this trouble is an accumulation of soil binder on top of a base that was not properly mixed during original construction. This accumulation must be removed, replaced with granular material, compacted, and primed before replacing the surface course.

(*c*) Joints and cracks in concrete slabs must be repaired by sealing them with hot asphalt or tar. Complete joint maintenance is done during favorable dry weather; once in the spring to correct damage that occurred during the previous winter, and again early in the fall to prepare the pavement for the next winter. Depressed and broken slabs resulting from ordinary foundation settlement are resurfaced with bituminous premix to bring the runway surface back up to grade. The area to be resurfaced is first cleaned, then a light tack coat of RC-3 cut-back asphalt or RS-1 emulsified asphalt is applied at about 0.1 gallon per square yard. The premix is then spread to required thickness by hand raking. The edges of the patch are "feathered out" by raking to eliminate any bumps or ridges, and the whole patch is compacted by rolling. Broken slabs resulting from major foundation defects are replaced after the foundation is repaired.

e. Stockpiles.—Pits must be opened and stockpiles of sand and gravel, base material, and premix patching material must be prepared at convenient places and in ample quantities ready for emergency maintenance. These stockpiles must provide for quick loading and transportation to the runways. Loading traps or other improvised arrangements are prepared in advance (see figs. 125 and 126). The bucket elevator may be used in pits or at stockpiles.

f. Bituminous premix for patching.—A stockpile of premixed material must be available for emergency repairs of bombed pavements. Suitable premix consists of aggregate such as No. B, table XXIV, and MC-3 cut-back asphalt. Other bituminous products may be used if

MC-3 is not available (see tables XXXVII and XXXVIII). The proportion of bitumen added to the aggregate should be slightly more than the quantity determined by paragraph 118. In general the proportion of bitumen should be between 4 and 6 percent. The premix will be prepared at the time the first runway is being surfaced. See paragraph 122*e* for construction procedure.

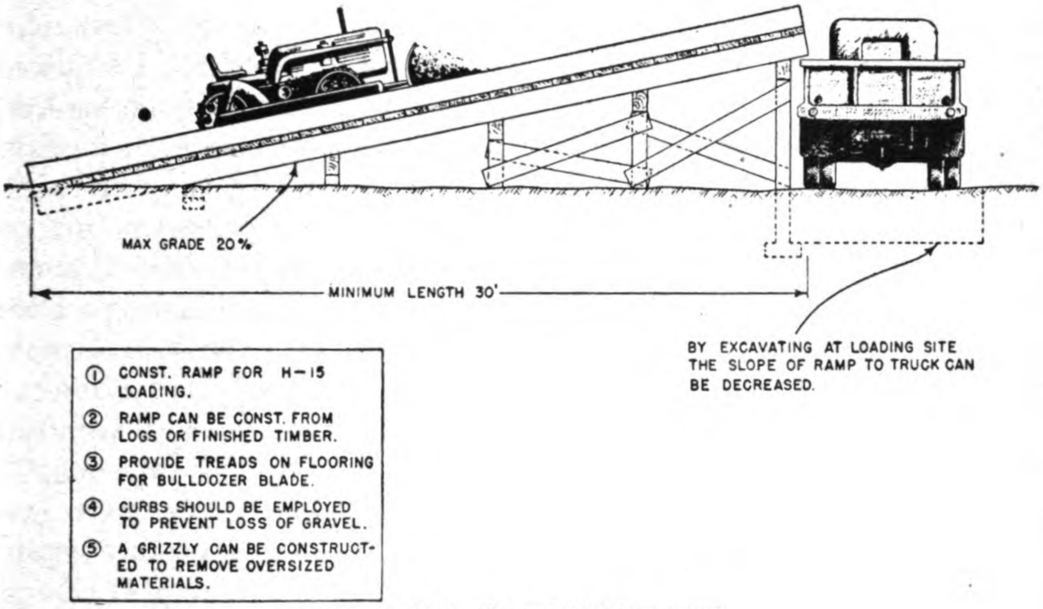

MAX GRADE 20%
MINIMUM LENGTH 30'
BY EXCAVATING AT LOADING SITE THE SLOPE OF RAMP TO TRUCK CAN BE DECREASED.
① CONST. RAMP FOR H-15 LOADING.
② RAMP CAN BE CONST. FROM LOGS OR FINISHED TIMBER.
③ PROVIDE TREADS ON FLOORING FOR BULLDOZER BLADE.
④ CURBS SHOULD BE EMPLOYED TO PREVENT LOSS OF GRAVEL.
⑤ A GRIZZLY CAN BE CONSTRUCTED TO REMOVE OVERSIZED MATERIALS.

FIGURE 125.—Gravel loading ramp.

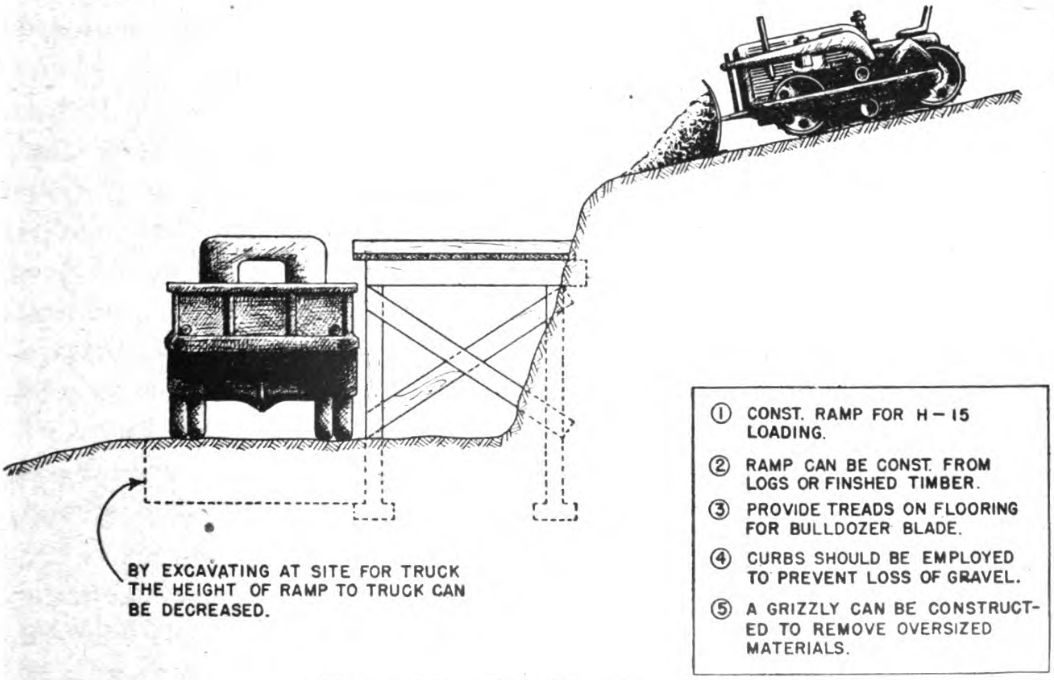

BY EXCAVATING AT SITE FOR TRUCK THE HEIGHT OF RAMP TO TRUCK CAN BE DECREASED.
① CONST. RAMP FOR H-15 LOADING.
② RAMP CAN BE CONST. FROM LOGS OR FINSHED TIMBER.
③ PROVIDE TREADS ON FLOORING FOR BULLDOZER BLADE.
④ CURBS SHOULD BE EMPLOYED TO PREVENT LOSS OF GRAVEL.
⑤ A GRIZZLY CAN BE CONSTRUCTED TO REMOVE OVERSIZED MATERIALS.

FIGURE 126.—Gravel loading ramp.

g. Snow.—(1) *General.*—Standing orders should cover responsibilities, priorities, safety precautions, and operational requirements with respect to snow and ice. Factors to be considered in planning the snow handling program are climatic conditions, aircraft to be accommodated, equipment available for handling snow, and camouflage requirements. Airplanes may be equipped with landing skis or wheels. Ski equipped airplanes operate successfully on packed snow, while airplanes with landing wheels can operate in not more than 3 inches of loose snow. This depth of loose snow may be fresh snow on a clear runway, fresh snow on previously packed snow, or melting snow previously packed on a runway. Maintenance operations must continually reduce the thickness of packed snow so that when a thaw comes there will be no more than 3 inches on the runway. From the standpoint of camouflage, it may be undesirable to remove all snow from a runway when the surrounding terrain is blanketed with snow.

(2) *Equipment.*—Equipment for handling snow consists of regular and special equipment organic with aviation engineers supplemented by other equipment selected to fill particular needs and issued from depots. Equipment from depots includes such pieces as V- and one-way push plows, rotary plows, rollers, and others specially developed for unusual snow conditions. Many expedients are workable in field operations.

(3) *Methods of packing.*—(*a*) In regions of heavy snowfall, with prolonged cold weather relatively free from sudden thaws, snow may be handled by packing. Rolling begins as soon as 3 inches of fresh snow have fallen, and continues during the snowfall. The packed snow is then dragged or scraped to smooth it. The runway, shoulders, and as much adjacent area as practicable are packed. Accumulated packed snow on runway and shoulders is removed as the season progresses so that a sudden thaw will not leave the runway covered with a blanket of soft snow too thick for airplane operation.

(*b*) Snow packing is accomplished with a set of three rollers drawn by tractor with snow treads. Each roller is 4 feet 8½ inches outside diameter, and 10 feet 3½ inches long with a shell of 10-gage corrugated metal. Over-all axle length of each roller is 11 feet 9 inches. The corrugated metal shell is supported on the axle by two structural frames or spiders at the third points and two steel plate bulkheads at each end. One of the plates has a manhole. The three rollers are arranged with one in front and two in line immediately behind the first. Each rear roller is attached by an A-frame to one end of the axle of the front roller, and the front roller is attached to the tractor by an **A**-frame. Dragging for smoothing after rolling is done with a tractor-drawn timber frame drag, equipped with metal cutting edges front and rear, or with a grader. Another type of roller that has been successfully used for packing snow for light airplanes is constructed mainly of wood, is 8 feet in diameter, 10 feet long, and weighs about 1,000 pounds. Two-inch pipe is used for the axle. Five circular ribs built of lumber 2 inches thick are mounted on the axle at 2½-foot intervals. These ribs are then covered with 1- by 4-inch boards placed longitudinally to form the surface of the roller.

(4) *Methods of clearing and removing.*—Clearing and removal of snow is required in regions where climatic conditions will not permit snow packing. Snow clearing may be accomplished with ballasted truck equipped with snow plow on the front, having a rolling caster at each end of the plow to keep it about ½ inch above the runway surface; grader; tractor with angledozer; tractor with one-way or **V**-type blade; and rotary snow plow. The truck and grader may be used for light snowfalls. They start at the center of the runway and progressively move the snow to the sides with each longitudinal trip. The tractor equipped with angledozer, or tractor with one-way snow blade is used to clear heavy snowfalls and to move windrows accumulated by the truck and grader. Drifts may be opened with the tractor with **V**-type blade or with the rotary snow plow. Rapid removal of heavy snow requires a rotary plow or other special equipment. In the absence of this equipment, as an expedient, snow may be loaded on a tractor-drawn sleigh built of timber. Even if rotary plows are available, sleighs may be used to remove necessary snow from work areas around hangars and shops.

h. Ice.—Ice coatings on runways, taxiways, and hard standings are treated with a sprinkling of sand spread by hand or by mechanical spreaders issued from depot stock. If practicable, sand should be heated before spreading. Salt (sodium chloride and calcium chloride) is not used for ice control on airdromes because it promotes corrosion of metal aircraft parts. Accumulated sand on runways and taxiways is removed in the spring by power brooming.

127. Special or emergency maintenance.—*a. Scope.*—Emergency maintenance after bombing requires quick repair and clearing of the principal runway and necessary connecting taxiways followed by repair of other facilities as needed. Speedy repairs depend largely on advance preparations and training and on the use of equipment rather than hand labor. Work should start immediately after the "all clear" signal. Meanwhile, hasty reconnaissance is necessary to survey the extent of damage and to establish priority of work. Air reconnaissance by the engineer as soon as possible after one runway is in operation is advisable to detect any damage or necessary maintenance overlooked in the ground reconnaissance.

b. Bomb craters.—(1) Principal work items are filling bomb craters and repairing and replacing damaged pavement on the principal runway and connecting taxiways. Average figures for amount of earth displaced by bombs are 90 tons for 300-pound bombs and 1,000 tons for 2,200-pound bombs. When dropped from very high altitudes, bombs sometimes penetrate deep and cause subterranean craters or "camouflets" which appear only as mounds on the surface. These cavities must be found, collapsed, and filled. Camouflets generally contain a poisonous gas, carbon monoxide (CO). Since the gas mask does not protect against this gas, care must be taken to protect personnel while collapsing camouflets. The opened crater must be ventilated before it is safe.

(2) The first operation in filling a crater is to push surrounding earth and debris from the undamaged runway area into the crater with an angledozer. This material is generally very fine grained. Admixing granular material during backfilling is advisable. Additional imported fill will be needed after all explosion debris is replaced. Stockpiled select material is used for this purpose. Continuous moistening and tamping for compaction are required, using machinery if practicable. When the crater is thus backfilled to within 6 or 8 inches of the runway surface, the perimeter of the crater is cut and trimmed vertically. Base material is then placed and compacted. Finally a bituminous premix surface is laid and compacted.

(3) Repaired craters must be inspected periodically for settlement, especially after the first rain.

c. Removing metal fragments.—Metal fragments on the runway from bombs or antiaircraft fire are a serious menace to airplane tires. They must be removed before airplanes operate. Removal may be effected by work parties in line across the runways and taxiways, working from one end to the other, picking up all fragments and collecting them in any handy receptacles, such as sandbags. Accompanying trucks can pick up filled sandbags.

d. Other repairs.—After the airdrome is back in operation, other needed repairs proceed. Meanwhile stockpiles are replenished for subsequent emergencies.

128. Steel runways.—Details concerning the repair and maintenance of steel runways are covered in chapter 9.

CHAPTER 12

PROTECTIVE CONSTRUCTION

	Paragraph
General	129
Types of projectiles	130
Terrain features	131
Camouflage	132
Simple protective measures	133
Blast and splinter resistant construction	134
Weapons emplacements	135
Structural considerations for surface and for semiburied shelters	136
Gasproofing	137
Protection against incendiary bombs	138
Aircraft revetments	139
Preservation of sandbags	140

129. General.—This chapter briefly covers typical defensive structures which aviation engineers may be required to build. For a detailed discussion of protective construction see TM 5-310 and FM 5-15.

130. Types of projectiles.—Enemy artillery is seldom in a position to fire on airdromes. Protective structures for airdromes are therefore designed to protect against aerial weapons. The following types of aerial weapons may be expected:

a. High explosive bombs.—These bombs cause destruction from fragments, blast effect, and earth shock.

b. Incendiary bombs.—These bombs are designed to cause destruction by fire. Incendiary bombs cause more damage to matériel in nondispersed areas than all other types together. They are generally nonexplosive, but often they contain a small charge to discourage personnel attempting to extinguish them.

c. Aerial mines.—Generally attached to parachutes, these missiles detonate by contact. Trees and overhead wires may set them off. Their destructive effect is due to blast rather than splinters.

d. Gas.—Gas may be sprayed from airplanes or may be dropped in bomb containers with instantaneous nose fuzes.

131. Terrain features.—Advantage must be taken of all terrain features. Such features may be used in their natural state to provide concealment and protection, or may be converted into protective structures.

132. Camouflage.—Concealment and dispersion must be planned from the first. In areas which are to be excavated and filled, all turf, sod, leaves, and forest humus are removed, set aside, and replaced after construction. Spoil is not placed indiscriminately on parapets or adjacent to structures but is disposed of in an inconspicuous manner. Fresh spoil must not be left uncovered. Fresh spoil and a regular outline together form a perfect signpost for aerial observers.

133. Simple protective measures.—When the engineer construction crew first arrives on a proposed airdrome site, simple entrenchments for personnel and for weapons will be set up. These protect personnel during air raids and provide ground organization for active defense against attack. Typical construction includes the following:

a. Prone shelters (fig. 127) are 2 feet wide, 2 feet deep, and long enough to permit the occupant to rest in a prone position. These shelters are dug rapidly and must take advantage of natural cover. They furnish protection from small-arms fire and from bomb fragments. Suitable for shelter during attacks by bombardment airplanes, they are not deep enough to protect against ground strafing.

b. Slit trenches protect against ground strafing. They are usually dug from 4 to 5 feet deep and are as narrow as possible to permit occupancy. The slit trench trace is usually a chevron or an L. This change of direction allows occupants to take shelter in the leg which is perpendicular to the direction of flight of the strafing airplane.

c. Fox holes (figs. 128, 129, and 130) may be built for one man or for two men. Fox holes differ from slit trenches in that they have a fire step and are wider, thus allowing the occupants to return fire.

d. Observation posts (fig. 131) may be nothing more than well-concealed fox holes. Observation posts are necessary for an effective alert system. Excellent lookout posts may be constructed in trees.

e. Weapons emplacements for machine guns and antitank guns (figs. 132 and 133). Aviation engineers are equipped with the .50 caliber machine gun, and 37-mm antitank gun but may be required to build pits for the 40-mm and 90-mm antiaircraft guns. Nets or other overhead cover should be used for these emplacements. All guns are sited to fire at both ground targets and aerial targets. Nets or cover used over them must be of a type which can be removed rapidly to enable the gunners to follow aerial targets.

134. Blast and splinter resistant construction.—When work first starts on an airdrome site the protective construction mentioned in paragraph 133 may be sufficient for defense. As the construction nears completion and the airdrome becomes a vital installation, blast and

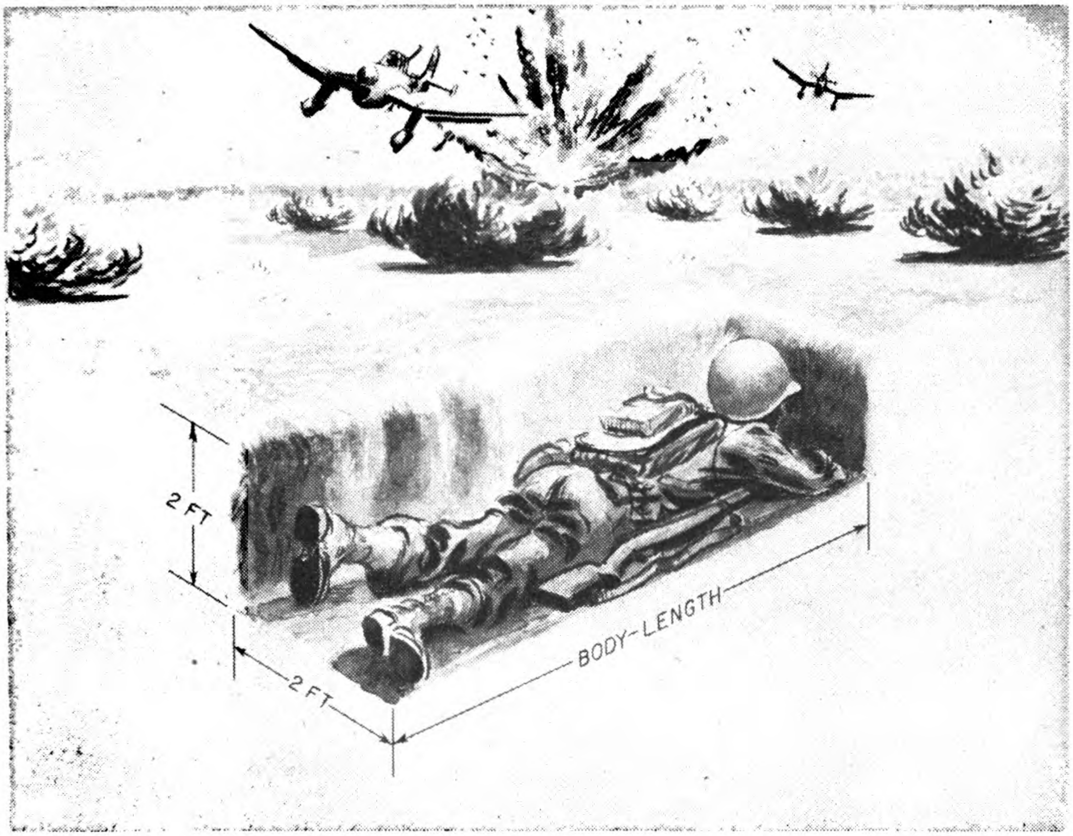

2 FT
2 FT
BODY-LENGTH

FIGURE 127.—Prone shelter—longitudinal section (perspective).

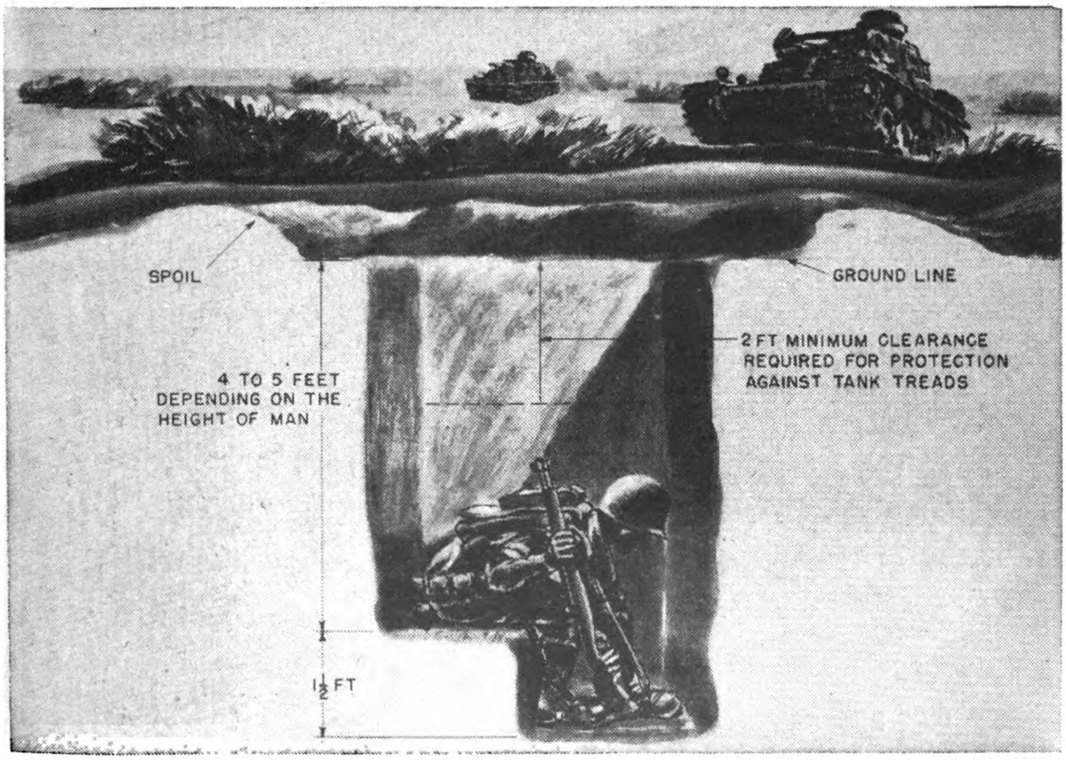

SPOIL
GROUND LINE
2 FT MINIMUM CLEARANCE REQUIRED FOR PROTECTION AGAINST TANK TREADS
4 TO 5 FEET DEPENDING ON THE HEIGHT OF MAN
1½ FT

FIGURE 128.—One-man fox hole—longitudinal section.

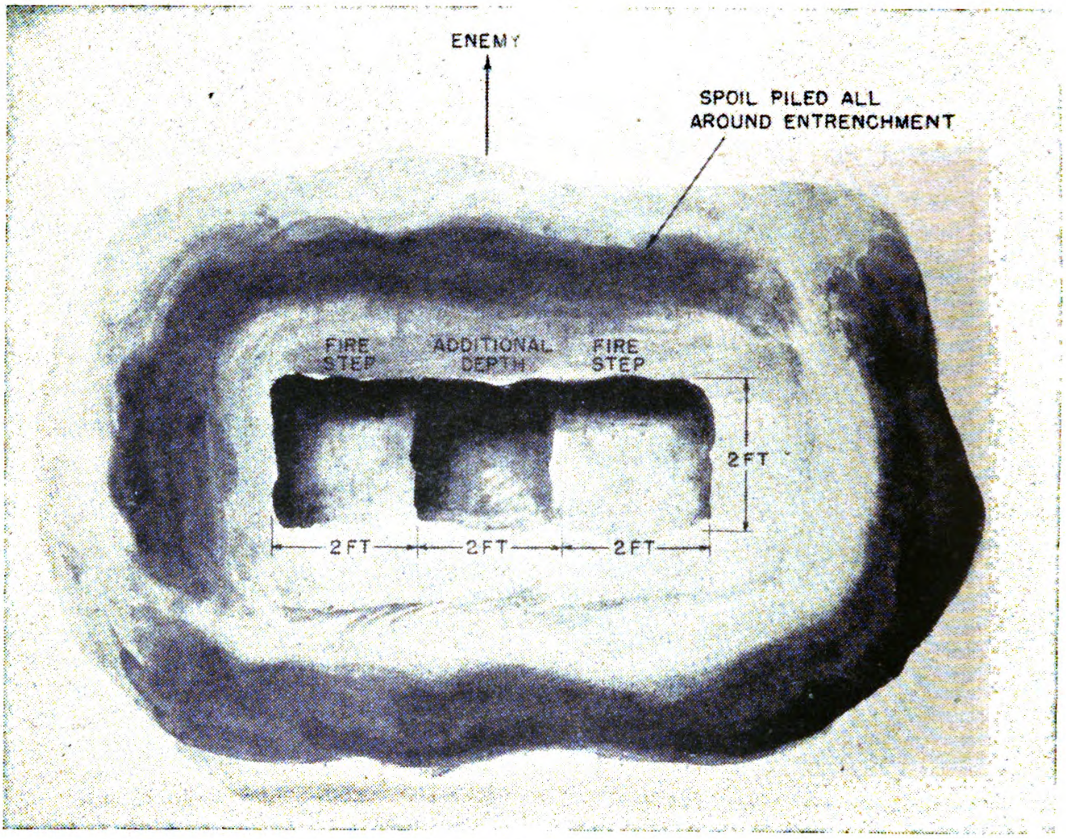

ENEMY
SPOIL PILED ALL AROUND ENTRENCHMENT
FIRE STEP
ADDITIONAL DEPTH
FIRE STEP
2 FT
2 FT
2 FT
2 FT

FIGURE 129.—Two-man fox hole plan. Fox hole should be camouflaged.

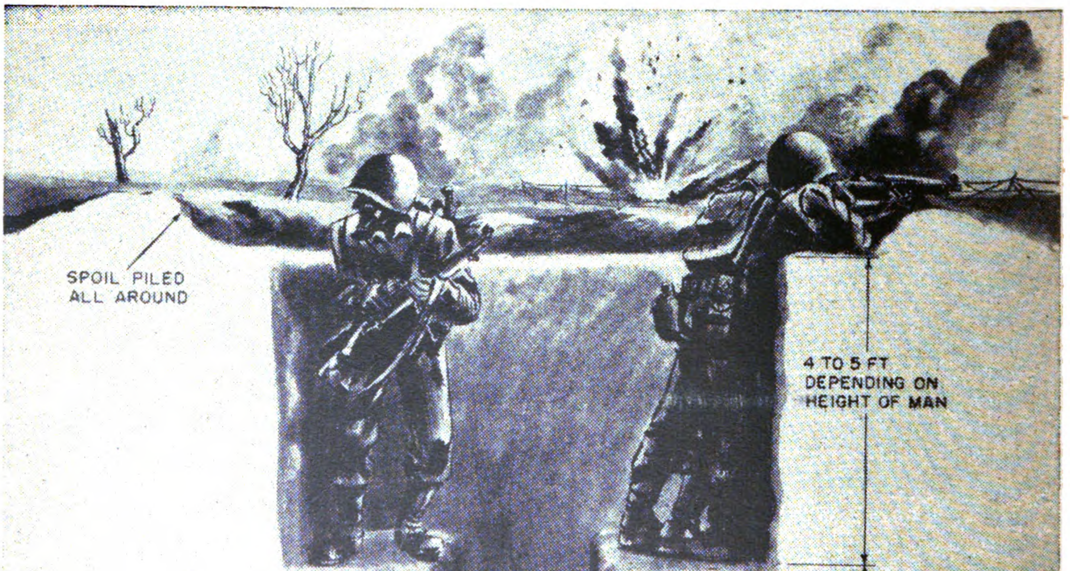
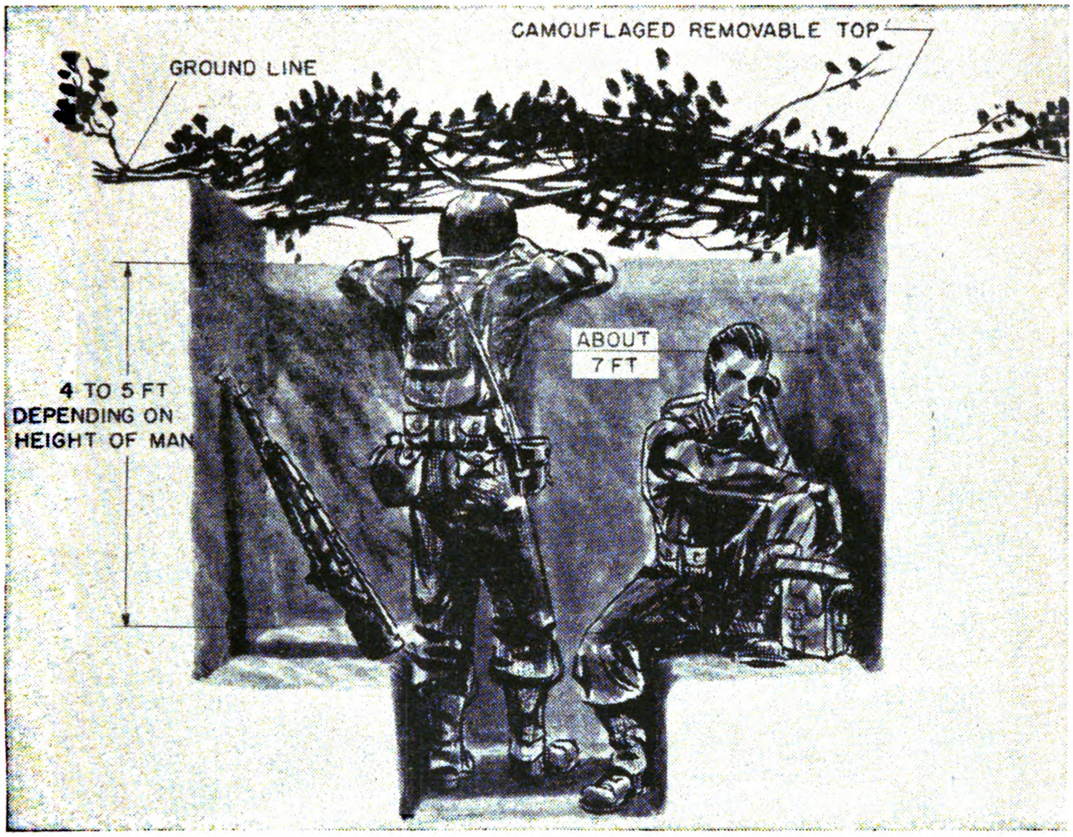
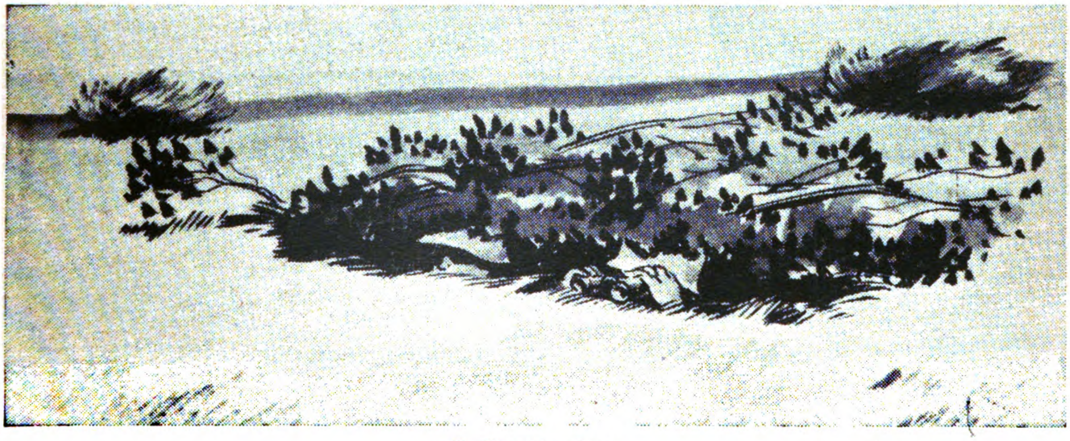

SPOIL PILED ALL AROUND
4 TO 5 FT DEPENDING ON HEIGHT OF MAN
1½ FT
2 FT
2 FT
ABOUT 6FT

FIGURE 130.—Two-man fox hole—longitudinal section.

splinter resistant construction may be necessary. The prone shelters, slit trenches, and fox holes are not abandoned but are used in conjunction with the new construction.


CAMOUFLAGED REMOVABLE TOP
GROUND LINE
ABOUT 7 FT
4 TO 5 FT DEPENDING ON HEIGHT OF MAN

① Rear view.



② Front view.

FIGURE 131.—Observation post, utilizing a two-man fox hole.

135. Weapons emplacements.—For a detailed discussion of blast and splinter resistant weapons emplacements see FM 5–15. One type of protected weapons emplacement is illustrated in figure 134. The type illustrated can be adapted with slight modifications to any size of machine gun. Details of reinforcing steel are not shown.

136. Structural considerations for surface and for semi-buried shelters.—Blast and splinter resistant structures may be erected completely above ground, or they may be partially buried. The forces to be resisted and the degree of protection practicable are the same in either case. General design features applicable to both types follow:

a. Structures should be dispersed and placed on slopes of hills where possible. There should be a minimum of 50 feet between adjacent buildings.

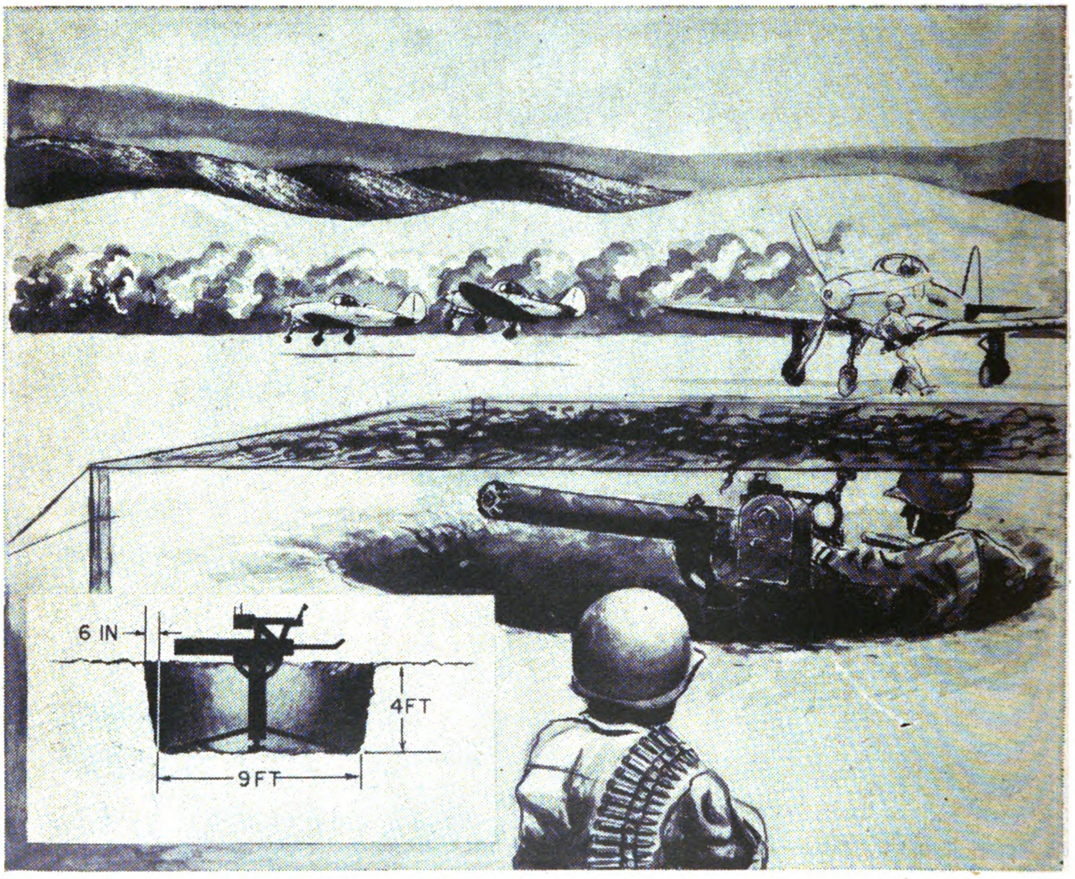


FIGURE 132.—Caliber .50 antiaircraft machine-gun emplacement.

b. Design will be to protect primarily against high explosive bombs. These bombs have destructive effects produced by fragments, blast, and earth shock (see par. 130).

(1) Fragments are parts of the bomb case broken off at explosion and moving at great speed. These fragments have considerable penetrative power. When a wall has been designed to stop fragments it is usually thick enough to protect against blast. Roofs and floors

are not usually as exposed to fragments as walls; therefore, they do not have to be so thick.

(2) Blast effect above ground travels in the form of pressure waves. Following the positive pushing wave there is a negative suction wave. Walls which have been designed to stop fragments are thick enough to stop blast, but the walls must be reinforced and they must be of rigid design.

(3) Earth shock occurs when a bomb is detonated underground. This shock travels in horizontal and vertical waves. If a bomb explodes near an underground structure the vertical wave, or earth movement, may reach the shelter before the horizontal wave. The vertical push will shove the roof up off the walls and allow it to fall back on the walls while they are in motion from the horizontal push. When this occurs the shelter will probably collapse. To protect against earth shock it is necessary to fasten floor and roof securely together.

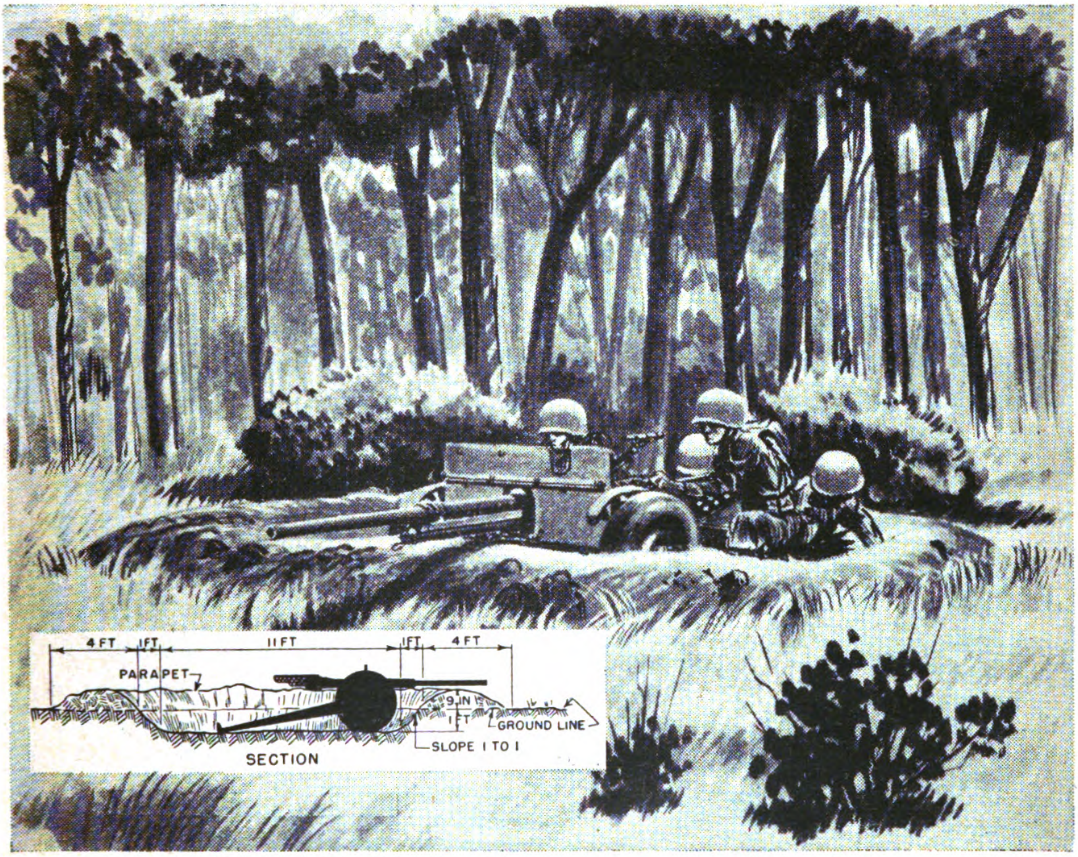


FIGURE 133.—37-mm antitank gun—emplaced for action.

c. Bombs larger than 550 pounds will normally not be wasted against a dispersed target such as an airdrome. Therefore usual design is for protection against the 500-pound or 550-pound bomb. Table XXVI shows thickness needed against other bombs as well.

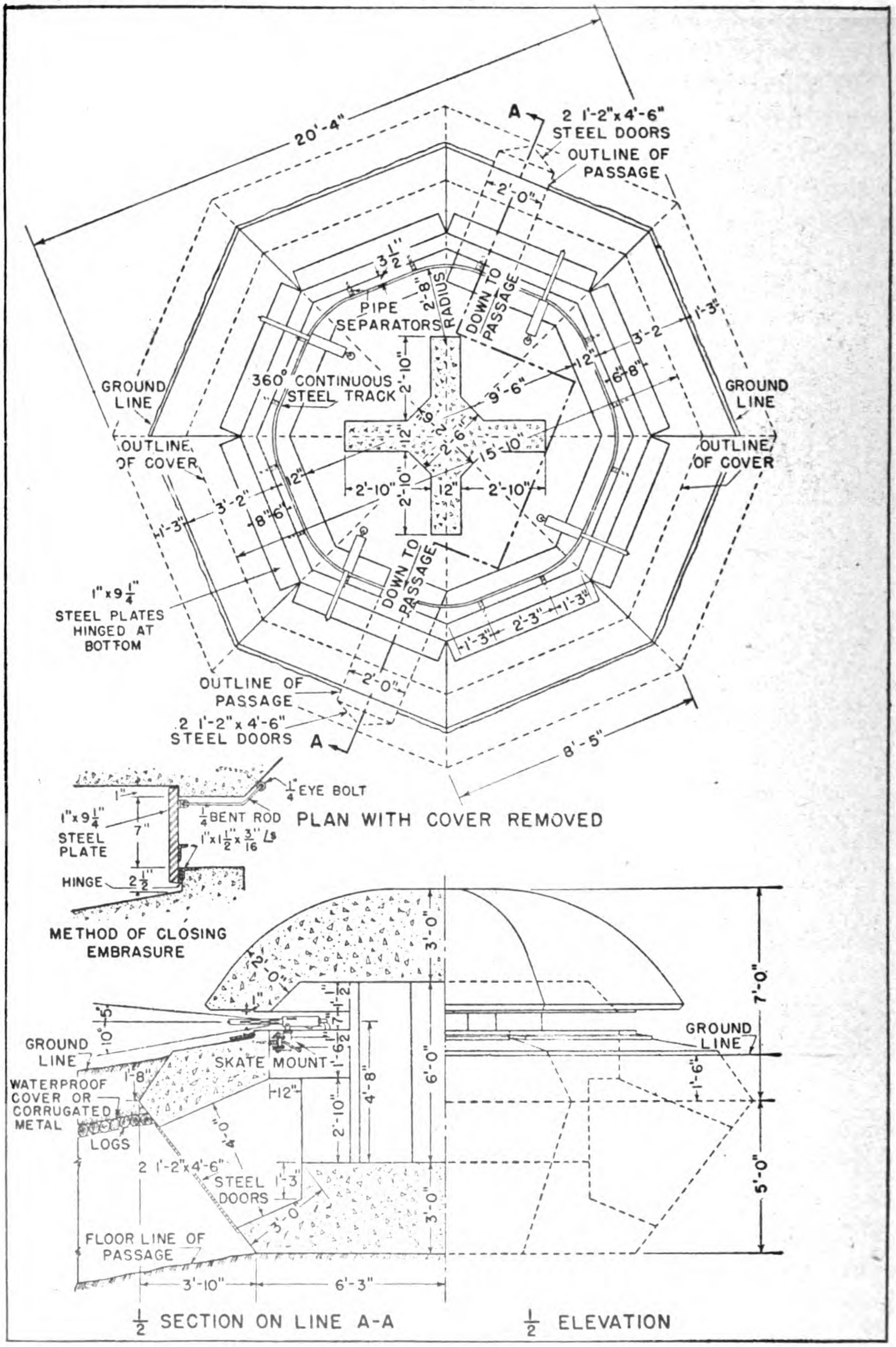

20'-4"
A
2 1'-2"x4'-6" STEEL DOORS
OUTLINE OF PASSAGE
2'-0"
3½"
2'-8" RADIUS
PIPE SEPARATORS
DOWN TO PASSAGE
1'-3"
3'-2
12"
6'-8"
2'-10"
360° CONTINUOUS STEEL TRACK
9'-6"
GROUND LINE
OUTLINE OF COVER
12"
2'-6"
15'-10"
12"
2'-10"
12"
2'-10"
3'-2"
8'-6"
1'-3"
1"x9¼" STEEL PLATES HINGED AT BOTTOM
DOWN TO PASSAGE
2'-3"
1'-3"
1'-3"
2'-0"
OUTLINE OF PASSAGE
2 1'-2"x4'-6" STEEL DOORS
8'-5"
¼" EYE BOLT
¼ BENT ROD
1"x1½"x3/16" L's
1"x9¼" STEEL PLATE
1"
7"
HINGE
2½"
PLAN WITH COVER REMOVED
METHOD OF CLOSING EMBRASURE
2'-0"
3'-0"
7'-0"
10°-5°
1"
1½"
7"
1½"
GROUND LINE
SKATE MOUNT
1'-6"
1'-8"
WATERPROOF COVER OR CORRUGATED METAL
LOGS
12"
4'-0"
2'-10"
4'-8"
6'-0"
1'-6"
GROUND LINE
2 1'-2"x4'-6" STEEL DOORS
1'-3"
3'-0"
3'-0"
5'-0"
FLOOR LINE OF PASSAGE
3'-10"
6'-3"
½ SECTION ON LINE A-A
½ ELEVATION

FIGURE 134.—Reinforced concrete emplacement for caliber .30 air-cooled machine gun.

TABLE XXVI.—*Thickness of materials to protect from fragments of bombs of all types exploding at a distance of 25 feet*

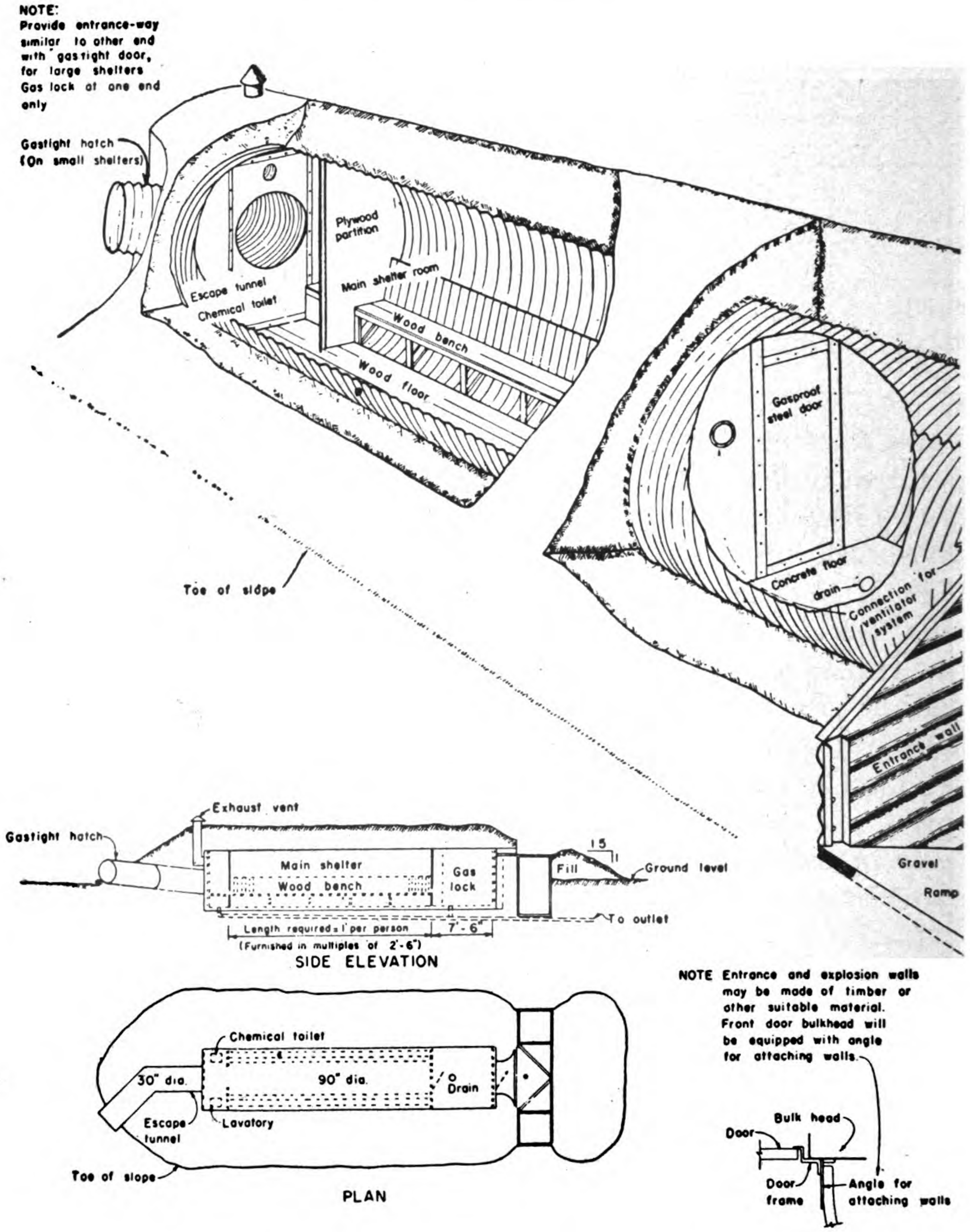
Bomb weight (pounds)	Mild steel (inches)	Sand, earth, or gravel (inches)	Brickwork (inches)	Reinforced concrete (inches)
110	1	30	12	10
220	1½	36	16½	15
550	2½	48	16½	15
1,100	3	48	16½	15
2.200	3½	54	16½	15

These thicknesses are for lateral and overhead protection where exposed to direct blast and splinters. Surface shelters with no overhead obstructions near do not need the full protective thickness overhead.

d. Of the materials usually available, reinforced concrete is the most efficient protection against military projectiles. Concrete is not available in many theaters of operations so that other materials must be substituted. Walls of rigid wooden frame construction, while not as resistant to splinters as walls of brick load-bearing construction, are more resistant to blast. Corrugated iron "elephants" are well suited for semiburied structures. Tests are under way on wood culverts similar in shape to corrugated iron sections. No matter what material is used, *the most important design feature is rigidity—the walls and roof must be securely tied.* If maximum protection is to be obtained in reinforced concrete construction this means welding the reinforcing rods where they lap.

e. Entrances must be protected by baffle or screening walls of the types illustrated in figure 136. These walls reduce blast pressure and keep fragments from entering the structure. At least two exits are provided for each structure.

f. Ventilation for structures which are not gasproofed is usually secured with several roof vents. Doors will not provide sufficient ventilation during continued occupancy. Structures which are gasproofed should use the protective collector issued by the Chemical Warfare Service for mechanical ventilation. Table XXVII gives minimum ventilation and space requirements for shelters.

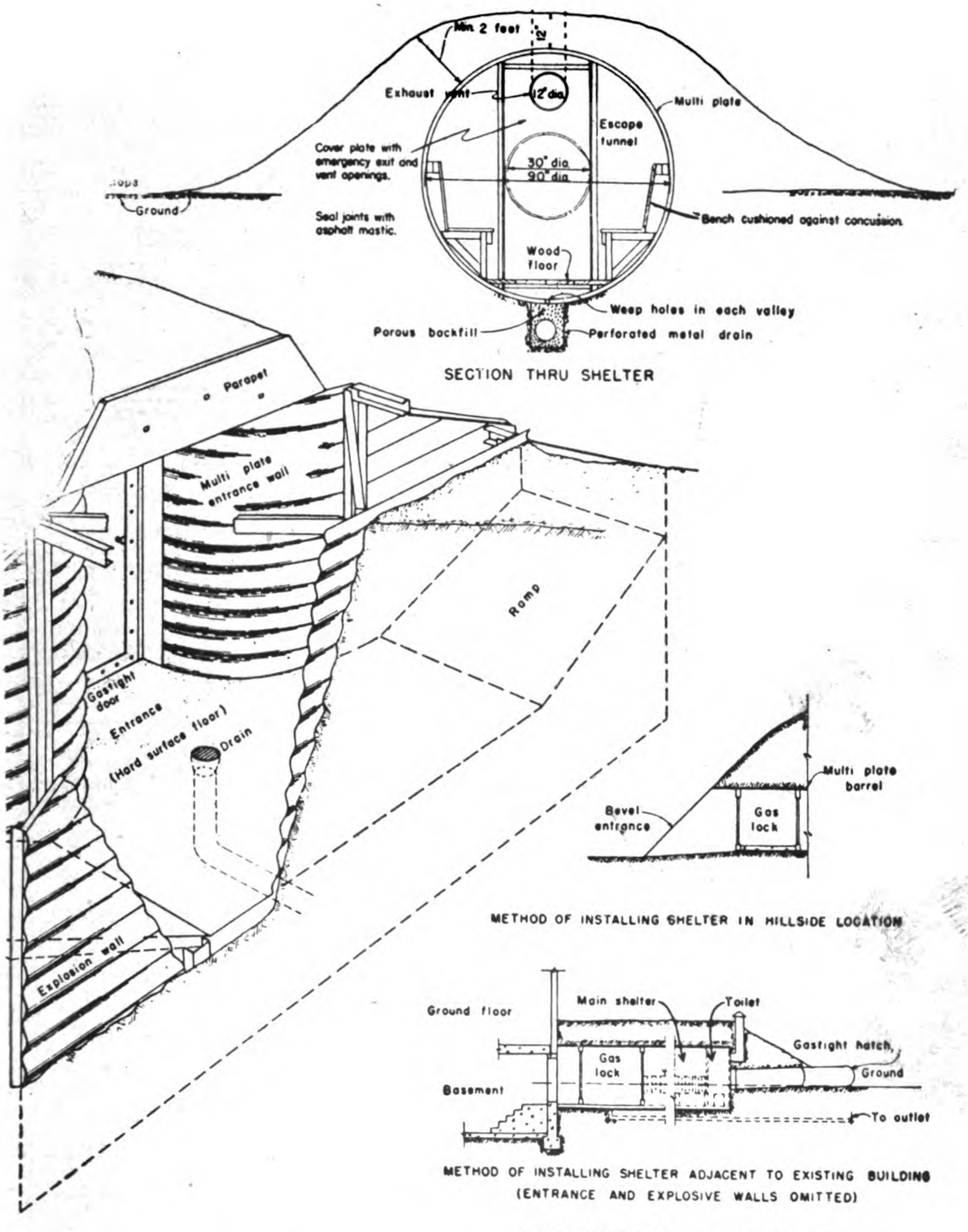


NOTE: Provide entrance-way similar to other end with gastight door, for large shelters. Gas lock at one end only

NOTE Entrance and explosion walls may be made of timber or other suitable material. Front door bulkhead will be equipped with angle for attaching walls.

Gastight hatch (On small shelters)
Escape tunnel
Chemical toilet
Plywood partition
Main shelter room
Wood bench
Wood floor
Toe of slope
Gasproof steel door
Concrete floor
drain
Connection for ventilator system
Entrance wall
Gravel
Ramp
Exhaust vent
Gastight hatch
Main shelter
Wood bench
Gas lock
Fill
1.5
1
Ground level
To outlet
Length required = 1' per person
(Furnished in multiples of 2'-6")
7'-6"
SIDE ELEVATION
Chemical toilet
30" dia.
90" dia.
Drain
Escape tunnel
Lavatory
Toe of slope
PLAN
Bulk head
Door
Door frame
Angle for attaching walls

FIGURE 135.—Splinterproof air raid


Min. 2 feet
12"
Exhaust vent
12" dia.
Multi plate
Escape tunnel
Cover plate with emergency exit and vent openings.
30" dia.
90" dia.
Ground
Seal joints with asphalt mastic.
Bench cushioned against concussion.
Wood floor
Weep holes in each valley
Porous backfill
Perforated metal drain
SECTION THRU SHELTER
Parapet
Multi plate entrance wall
Ramp
Gastight door
Entrance
(Hard surface floor)
Drain
Explosion wall
Multi plate barrel
Bevel entrance
Gas lock
METHOD OF INSTALLING SHELTER IN HILLSIDE LOCATION
Main shelter
Toilet
Ground floor
Gas lock
Gastight hatch
Ground
Basement
To outlet
METHOD OF INSTALLING SHELTER ADJACENT TO EXISTING BUILDING
(ENTRANCE AND EXPLOSIVE WALLS OMITTED)

Based on design submitted by a leading culvert manufacturer

shelter—corrugated metal type.

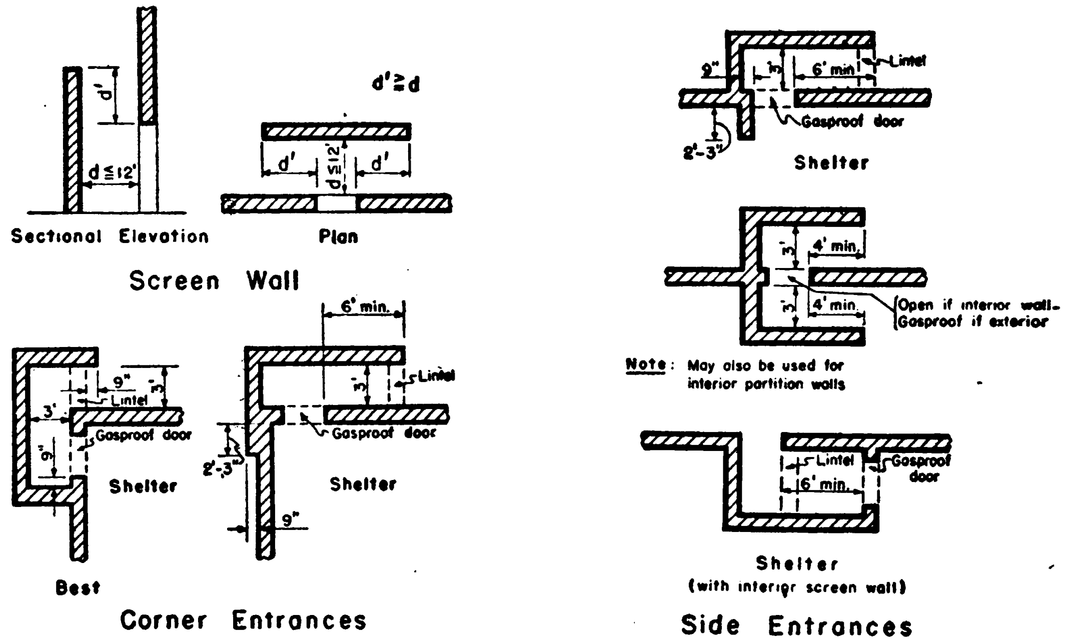

d'
d≤12'
d'≥d
d'
d≤12'
d'
Sectional Elevation
Plan
Screen Wall
9"
3'
Lintel
Gasproof door
Shelter
Best
6' min.
Lintel
Gasproof door
2'-3"
Shelter
9"
Corner Entrances
9"
6' min
Lintel
Gasproof door
2'-3"
Shelter
4' min.
4' min.
Open if interior wall-
Gasproof if exterior
Note: May also be used for interior partition walls
Lintel
Gasproof door
6' min.
Shelter
(with interior screen wall)
Side Entrances

FIGURE 136.—Baffle walls for entrances.

TABLE XXVII.—*Minimum ventilation and space requirements for shelters*

NATURAL VENTILATION (OPEN TO OUTSIDE AIR)

Location of shelter	Maximum period of occupancy (hr.)	Ventilation rate (cu. ft./hr./person)	Total surface area (sq. ft./person)	Floor area (sq. ft./person)	Volume content (cu. ft./person)
Above ground	3	----------	30	6	50
Above ground	12	----------	60	6	75
Below ground	3	----------	30	6	50
Below ground	12	----------	50	6	75
Above ground	3	Gastight (none).	75	6	120
Below ground	12	Gastight (none).	100	6	350
MECHANICAL VENTILATION					
Above ground	----------	300	40	8	60
Below ground	----------	300	30	8	60

NOTE.—The above figures are based on occupied space only such as passageways, sanitary arrangements, entranceways (gas locks, etc.); first-aid and decontamination rooms are not included.

137. Gasproofing.—The following information concerning gasproofing is taken from TM 5-310. For additional information see TM 5-310 and FM 21-40.

a. General.—(1) Structural protection against the chemical agents

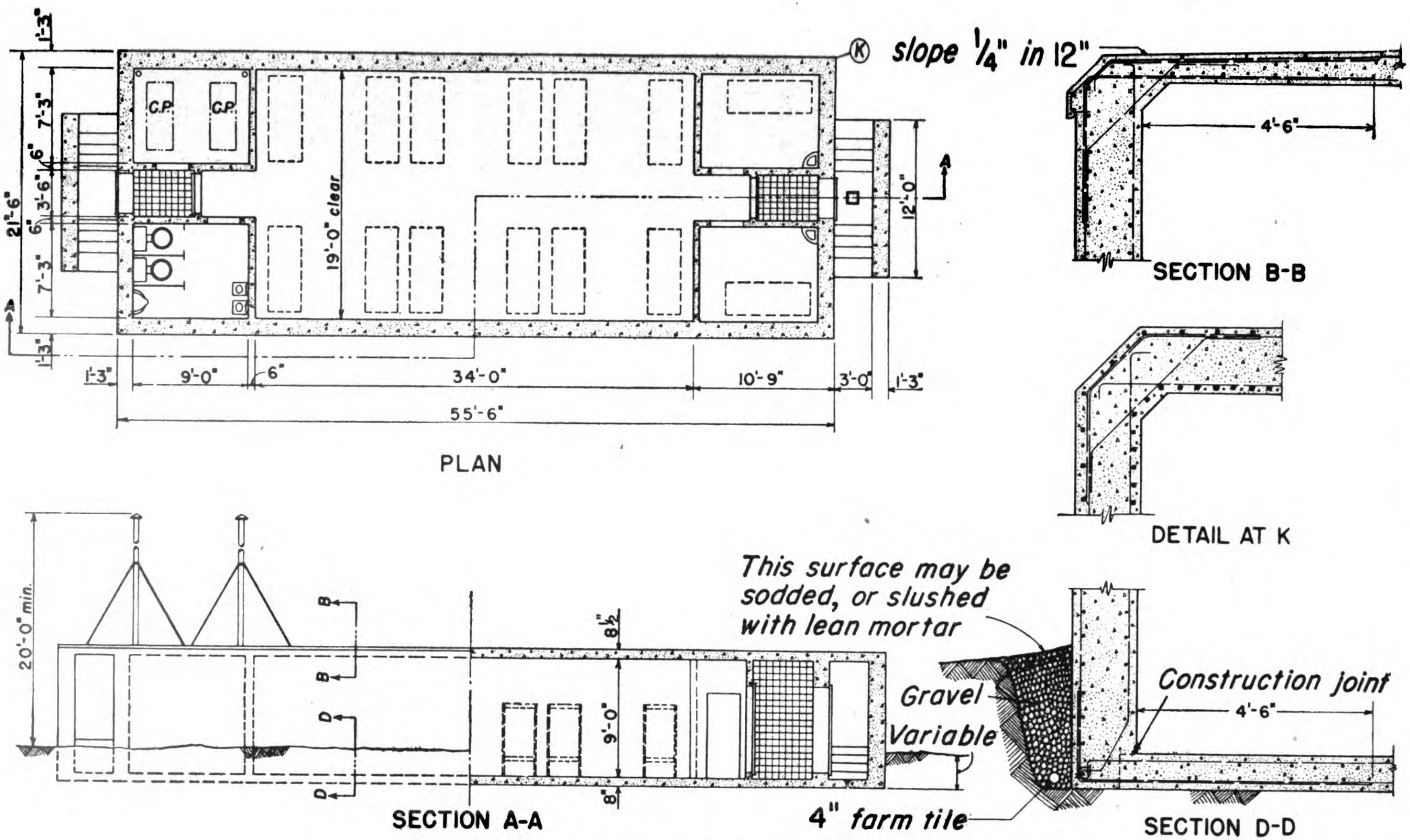

slope 1/4" in 12"
K
C.P.
C.P.
19'-0" clear
12'-0"
A
A
1'-3"
7'-3"
6"
3'-6"
6"
7'-3"
1'-3"
21'-6"
1'-3"
9'-0"
6"
34'-0"
10'-9"
3'-0"
1'-3"
55'-6"
PLAN
4'-6"
SECTION B-B
DETAIL AT K
20'-0" min.
B
B
D
D
8½"
9'-0"
8"
SECTION A-A
This surface may be sodded, or slushed with lean mortar
Gravel
Variable
4" farm tile
Construction joint
4'-6"
SECTION D-D

FIGURE 137.—Blast and splinter resisting structure for 26 men.

usually grouped under the term "gas," and which may be gases, liquids, or finely divided solid matter, must be separated into two classifications: protection to structural materials and protection to personnel.

(2) The protection of roads and buildings from the effects of chemical agents, excluding incendiary agents, requires a knowledge of gas action on various construction materials. Porous substances, such as brick or concrete, fairly readily absorb liquid mustard gas; chlorine and phosgene in particular attack metals, and some other gases are also solvents of some bituminous materials, especially those where gas works products were incorporated in the process of manufacture. Decontamination of roads, walls, floors, and roofs of buildings is facilitated when gas-resistant bituminous materials, rustproof sheet metals, and glazed tile facings are used.

(3) Protection to personnel may be further classified as individual, tactical, and collective protection. Individual protection is given by gas masks and special clothing. Tactical protection is gained by the movement of troops to uncontaminated areas. Collective protection is obtained by preventing the entry of gases into structures occupied by personnel who cannot efficiently perform their duties wearing gas masks, and by providing facilities for the antigas treatment of casualties. This protection must be provided for vital installations at airdromes.

(4) A satisfactory method of collective protection must keep gas out of the structure for definite periods, and must also provide sufficient fresh air for the occupants. These requirements may be satisfied by the construction of airlocks (two gasproof doors) at all entrances into the protected space; by making the structure reasonably airtight; and by installing the electrically operated MI collective protector, a standard piece of equipment issued by the Chemical Warfare Service. These collective protectors, which for safety should be provided with alternative sources of power and spare filters, have a capacity of 12,000 cubic feet of air per hour, sufficient for 20 men working in an operations room under most conditions. In hot weather the incoming air should be dehumidified by mechanical or chemical means. By maintaining a positive pressure in the protected space, the purified air leaks out and prevents contaminated air from leaking in. These collective protectors are supplied for a specific purpose, are expensive, and, to produce satisfactory results with proper regard to their capabilities and limitations, must be kept in good working order along with the auxiliary equipment.

(5) The gasproofing of existing buildings is necessarily of a makeshift nature. New construction can be made more nearly ideal for

gasproofing purposes, as the most effective details can be incorporated at the start, thus obtaining a much more efficient structure for protection against gas attack.

b. Locations.—(1) The gasproofed space itself, if placed in existing buildings, should be located as far as possible away from light or air shafts where heavy concentrations of gas could possibly remain.

(2) The collective protector is to be placed in or adjacent to the airlocks, and separated by means of a wall from the protected space. The air outlet should be placed so that the tendency of the air is to flow out of the structure due to the positive pressure, past the toilets and through the decontamination areas and airlocks out into the open air. One-way valves set to the positive pressure attained should be placed in the gasproof doors to permit this. The air intake should be placed at least 20 feet above the surface of the ground.

c. Open entrenchments.—If open entrenchments are used they should always be located on the highest terrain available to prevent the settling of the gas clouds, which are heavier than air, in the dugouts and low places.

d. Pipes entering structures.—All water and gas pipes and electrical conduits entering the shelters must be valved or arranged to prevent the entry of combat gases in the event the pipes are shattered outside the structure.

e. Doors.—(1) Doors are to be designed for a horizontal pressure of 100 pounds per square foot when properly screened from blast.

(2) In the event that no screen walls are used, the gasproof door should be staggered in respect to the blast and splinterproof door so that splinters that may possibly pass through the latter door will not strike the gasproof door.

138. Protection against incendiary bombs.—In nondispersed areas subject to constant aerial attack, incendiary bombs cause more damage to buildings than all other types of bombs.

TABLE XXVIII.—*Materials giving protection against burning by the 2.2-pound magnesium incendiary bomb*

Material	Minimum layer (in.)	Weight per square foot (lb.)
Concrete (including cinder concrete)	1	12 or less
Dry, virgin earth (sifted)	1¼	6. 0
Brick dust	1½	9. 5
Dry sand	1¾	13. 5

a. Construction materials.—Various fireproof materials have been developed but they are seldom available. The materials listed in table XXVIII are effective provided they are kept in place. If they are loose and exposed to the elements they may wash away or blow away.

b. Storage of inflammables.—All spaces vulnerable to incendiary attack must be cleared of wooden goods, waste paper, and oily waste. In warehouses, inflammable materials are stored in small stacks with wide aisles left to permit passage of fire-fighting equipment and to confine fire to small areas.

c. Fire plan.—A fire plan which will provide for quick treatment of fires must be prepared. Definite assignments to fire-fighting crews should be made, fire-fighting equipment should be spotted where it will be picked up and used, and practice fire drills should be organized to assure fire-fighting efficiency.

139. Aircraft revetments.—*a. General.*—Concealment and dispersion are the first steps in protection of airplanes on the ground. Elaborate revetments for aircraft protection are seldom constructed. Revetments afford protection against bomb fragments from high altitude bombing but do not prevent effective ground strafing; in fact they may draw fire if not well concealed. The air force commander will determine whether or not revetments will be constructed. A War Department order prohibits construction of revetments in the continental United States without specific authority. Requests for such authority will explain why adequate protection cannot be secured through dispersion.

b. Standard designs.—Figures 138 and 139 illustrate standard revetment designs. Designs for a crew shelter in the revetment wall must include both a front and rear entrance to the shelter; otherwise, a burning airplane inside the pen might trap the crew. Earth traverses are much stronger if cement stabilized soil is used. Sandbags should be rotproofed or filled with cement stabilized soil.

c. Sandbag reveting.—Unless sandbags used for reveting are carefully placed they will not stay in position. Proper methods of placing sandbags are shown in figure 140. A header is a sandbag placed perpendicular to the surface being reveted, while a stretcher is placed parallel to the surface.

140. Preservation of sandbags.—Ordinary sandbags should be used for temporary reveting only. Where bags are to be in place for a month or longer under average rainfall conditions they must be rotproofed or filled with soil partially stabilized with cement or bitumen. The later method is usually easier in the field. The following methods of mildew proofing and rotproofing sandbags in the field are listed in the order of their effectiveness:

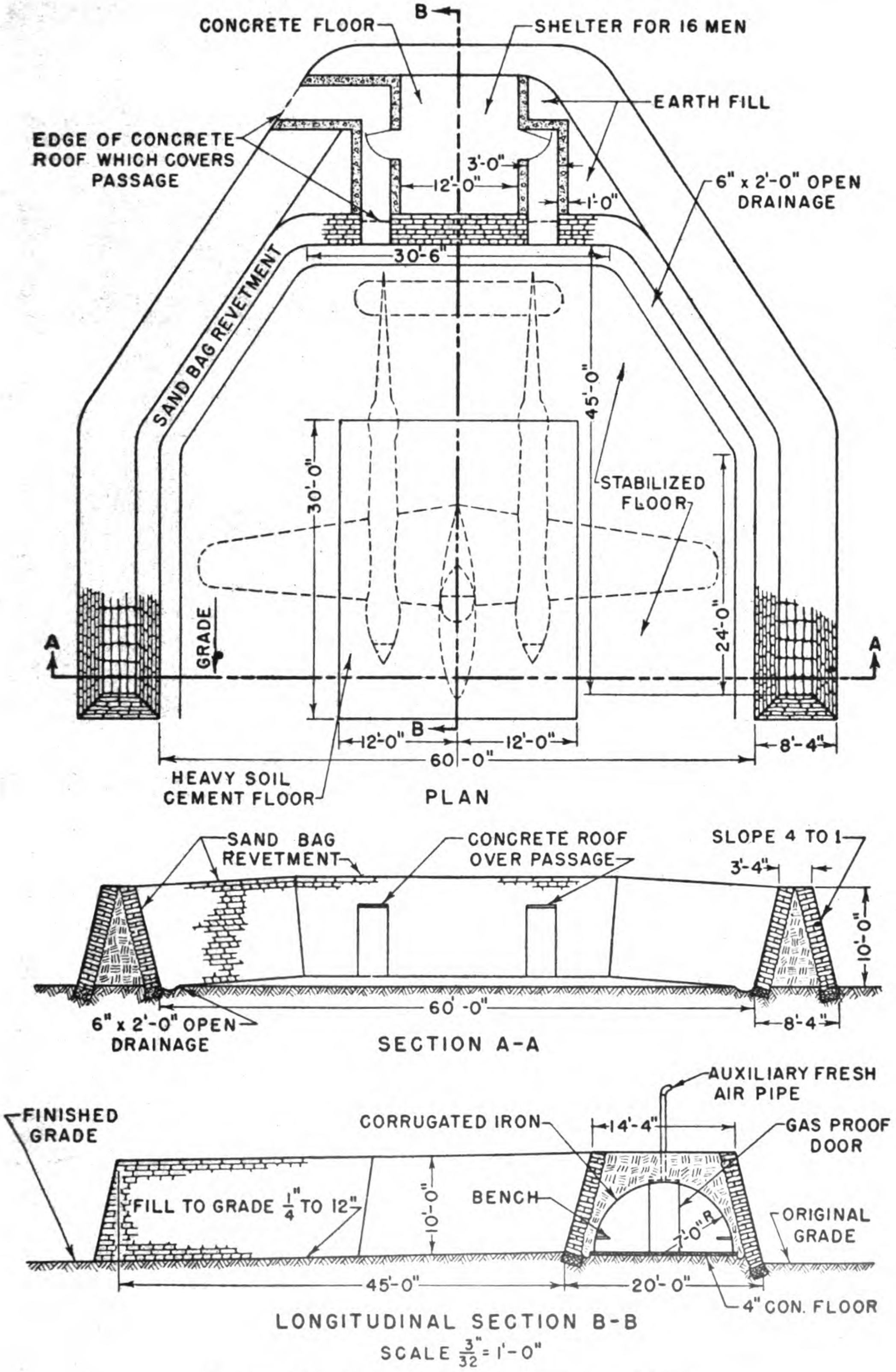
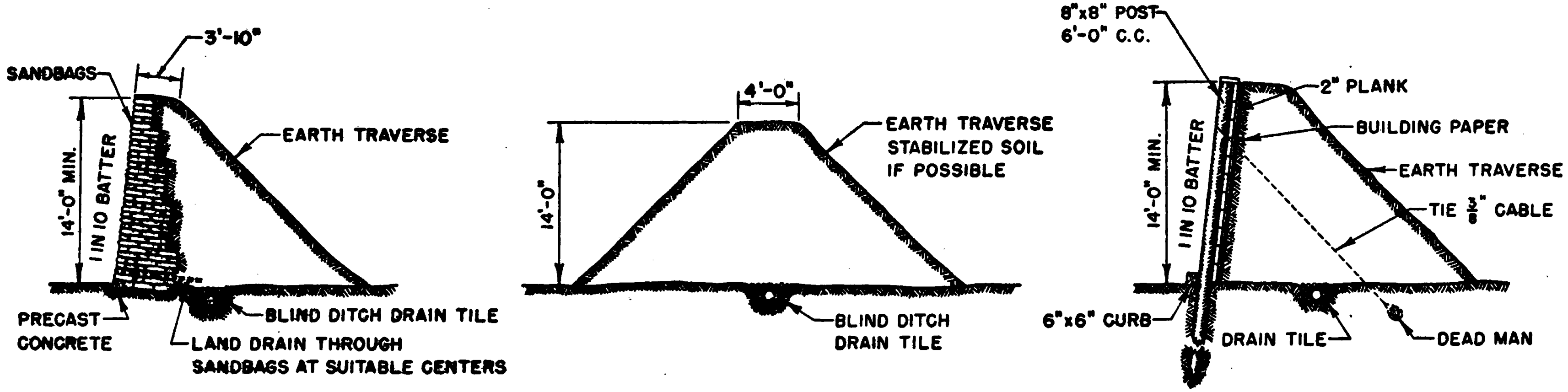

B
CONCRETE FLOOR
SHELTER FOR 16 MEN
EARTH FILL
EDGE OF CONCRETE ROOF WHICH COVERS PASSAGE
3'-0"
12'-0"
1'-0"
6" x 2'-0" OPEN DRAINAGE
30'-6"
SAND BAG REVETMENT
45'-0"
STABILIZED FLOOR
30'-0"
24'-0"
GRADE
A
A
B
12'-0"
12'-0"
60'-0"
8'-4"
HEAVY SOIL CEMENT FLOOR
PLAN
SAND BAG REVETMENT
CONCRETE ROOF OVER PASSAGE
SLOPE 4 TO 1
3'-4"
10'-0"
60'-0"
8'-4"
6" x 2'-0" OPEN DRAINAGE
SECTION A-A
AUXILIARY FRESH AIR PIPE
FINISHED GRADE
CORRUGATED IRON
14'-4"
GAS PROOF DOOR
FILL TO GRADE 1/4" TO 12"
10'-0"
BENCH
7'-0" R
ORIGINAL GRADE
45'-0"
20'-0"
4" CON. FLOOR
LONGITUDINAL SECTION B-B
SCALE 3/32" = 1'-0"

FIGURE 138.—Revetment for one fighter airplane.


3'-10"
SANDBAGS
EARTH TRAVERSE
14'-0" MIN.
1 IN 10 BATTER
PRECAST CONCRETE
BLIND DITCH DRAIN TILE
LAND DRAIN THROUGH SANDBAGS AT SUITABLE CENTERS
4'-0"
14'-0"
EARTH TRAVERSE STABILIZED SOIL IF POSSIBLE
BLIND DITCH DRAIN TILE
8"x8" POST 6'-0" C.C.
2" PLANK
BUILDING PAPER
EARTH TRAVERSE
TIE 3/8" CABLE
14'-0" MIN.
1 IN 10 BATTER
6"x6" CURB
DRAIN TILE
DEAD MAN

ALTERNATE SECTION ALTERNATE SECTION ALTERNATE SECTION

FIGURE 139.—Typical cross sections for revetments.

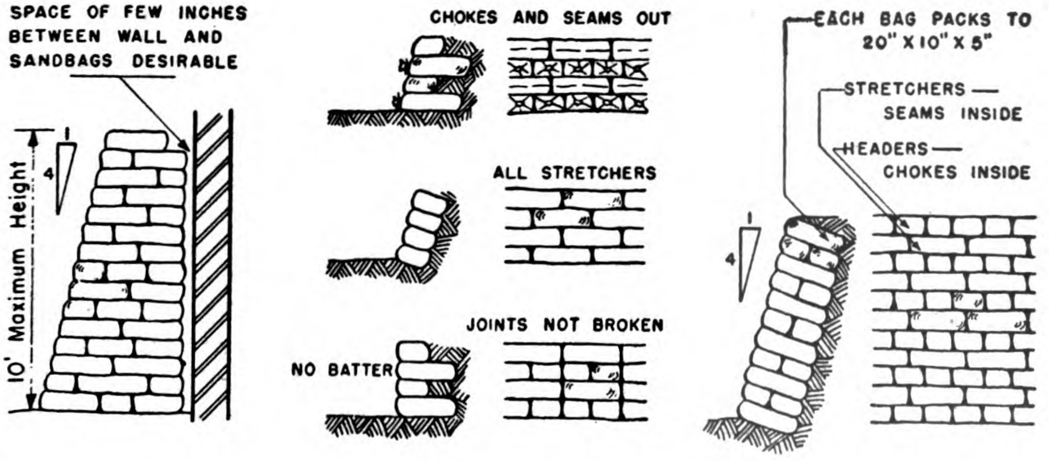
a. Ten percent of copper naphthenate by weight is dissolved in mineral spirits. Bags are soaked in resulting solution until a test shows an increase in weight of approximately 25 percent has been obtained. Bags are then allowed to dry.

b. Dissolve 20 pounds of copper sulphate in 10 gallons of water and add 2⅛ gallons of 28 percent ammonium hydroxide. The bags are dipped in this solution until their weight is increased approximately 40 percent, and then allowed to dry.

c. Bags may be dipped in fluid bituminous materials. These materials are cut-back asphalt, or cut-back tar diluted as needed, or a solution of 20 to 25 percent by weight of asphalt or tar in either gasoline or benzene. The exact amount and type of asphalt or tar must be determined by trial. The bag is soaked in solution to increase weight not to exceed 100 percent. A satisfactory result is obtained when the dried bag shows no stickiness.

d. Dissolve 4½ pounds of soda ash or 11½ pounds of soda crystal (sodium carbonate) in 5 gallons of water. Dissolve 10 pounds of copper sulphate in 30 gallons of water in a separate vessel and add 2 ounces of sulphonated pine oil. Dip the bags first in the soda solution and then in the copper sulphate solution, then allow the bags to dry.

e. Dilute asphalt emulsion with water so that bags dipped in the solution will dry to handle in 3 to 6 hours. This must be determined by trial.


SPACE OF FEW INCHES BETWEEN WALL AND SANDBAGS DESIRABLE
1
4
10' Maximum Height
CHOKES AND SEAMS OUT
ALL STRETCHERS
JOINTS NOT BROKEN
NO BATTER
EACH BAG PACKS TO 20" X 10" X 5"
STRETCHERS — SEAMS INSIDE
HEADERS — CHOKES INSIDE
1
4

Sandbag splinter and blast protection for wall

Wrong ways of revetting

Correct way of revetting

FIGURE 140.—Methods of reveting.

Chapter 13

DEFENSE OF AIRDROMES

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141. General.—*a.* Airdromes are primary targets for attack by hostile forces. Attacks may be made to neutralize an airdrome and prevent its use by friendly aircraft, or they may be made to seize the airdrome in order to use it as a point of departure for further air or ground operations.

b. The means made available for the defense of a particular airdrome depend on the type of attack to which it may be subjected and on the effect that its loss or neutralization will have on the tactical or strategical situation. There is no fixed method or means of defense.

c. This chapter covers ground defense only, so far as it may be participated in by aviation engineers. Additional references are FM 100-15, Training Circulars Nos. 47 and 73, 1941, and No. 31, 1942.

142. Responsibility.—The defense of an airdrome is an integral part of the defense of the entire area in which the airdrome is located. The theater or territorial commander assigns adequate mobile reserves to support the airdrome. He may also assign units from the ground forces for local defense of the airdrome. The airdrome commander is directly responsible for defense of the airdrome. He commands all units assigned for local defense and is responsible for their training and operation.

143. Troops available for defense.—*a.* Personnel available for defense of an airdrome may be grouped as follows:

(1) Ground crews, pilots, and flight crews off duty, and air force personnel connected with operation of the airdrome facilities; and quartermaster and ordnance personnel at the airdrome. Although primarily concerned with air force activities, they are trained in the use of infantry weapons. They may be used in close defense and in attacking disorganized parachute troops.

(2) Aviation engineers. Their duties are covered in paragraph 144.

(3) Air force defense units assigned to the airdrome. They include the air base security battalion (T/O 7-415) designed especially for airdrome defense to provide a fixed defense force and a mobile striking force; antiaircraft and searchlight batteries assigned to protect specific airdromes; and chemical warfare detachments, trained and equipped to combat chemical attack.

(4) Ground force units assigned to the airdrome for local defense.

(5) Mobile reserves from ground forces located where practicable to support two or more airdromes.

b. A typical airdrome might have the following available for defense:

(1) Personnel from two fighter squadrons based at airdrome, plus airdrome operational personnel and quartermaster and ordnance personnel.

(2) One company of aviation engineers.

(3) One air force security battalion (or one infantry battalion assigned for local defense in absence of a security battalion); one antiaircraft battery; and one chemical warfare platoon.

(4) One infantry regiment in reserve at some distance from airdrome.

144. Role of aviation engineers.—*a. Tactical.*—Aviation engineers are trained and equipped for combat. Personnel are armed with M1 rifles, pistols, carbines, and bayonets. Each company has four caliber .50 machine guns for protection against low-flying airplanes. Each company also has one 37-mm gun and one half-track. The 37-mm gun is primarily for use against light tanks and armored vehicles but may be used against gliders or air transports which have landed. The half-track is effective in mopping up small groups of airborne troops.

b. Technical.—Aviation engineers have important technical duties connected with airdrome defense. These duties are connected in general with organization of the ground and construction of protective structures. Included are camouflage, installation of defensive positions, construction of weapons emplacements, establishment of barriers for antimechanized defense and obstructions for preventing the landing of airborne troops, and demolition of the airdrome if capture becomes inevitable. These duties are planned and executed under engineer control in accordance with defense plans of the airdrome commander. Plans should be initiated as early as possible after movement into an area, even in the absence of instructions from higher authority. The engineer will obtain authority to proceed with this work if it becomes necessary.

145. Forms of attack.—Attacks against airdromes may take any one or combination of the following forms:

a. Sabotage.
b. Chemical attack.
c. Bombing and strafing.
d. Airborne attack.
e. Ground attack.

146. Sabotage.—The danger of sabotage is always present. Although standard methods of combating sabotage include riotproof fences and electrically charged fences, extensive fencing is seldom practical on field airdromes. Reliance must be placed on an alarm system and upon alert, aggressive, armed guards.

147. Chemical attack.—*a.* Chemical attack may be made with persistent gas, nonpersistent gas, toxic smoke, and screening smoke. Persistent gas, the most probable type of chemical attack, may be spread by bombs or spray from airplanes flying at any altitude. Screening smoke may be used in connection with airborne attack.

b. Gas sentinels and a gas alarm system are an essential part of the airdrome alarm system.

c. Protection against chemicals is obtained primarily by gas masks and protective clothing. Gas masks are carried or are immediately at hand at all times. Personnel should be issued protective clothing impregnated against persistent chemicals. Decontamination crews must have impermeable clothing. Protective ointment should be available for neutralizing liquid vesicant which may get on the skin.

d. Runways contaminated with gas are a major problem. Chief item of equipment for their neutralization is the 300-gallon power driven, decontaminating apparatus. This unit has a wide spray for covering runways with decontaminating agent. Bomb craters and equipment are decontaminated with hand apparatus. Chemical warfare personnel may be available for decontamination squads, but engineer troops will be trained for such work. For training and other information regarding chemical attack see FM 21-40 and Training Circular No. 31, W.D., 1942.

e. Methods of gasproofing are covered briefly in chapter 12. The existence of gasproof installations does not remove the necessity for protective measures listed in paragraphs 144, 145, and 146.

148. Bombing and strafing.—The types and effects of bombs are covered in chapter 12. Bombing may be from high or low altitude airplanes or from dive bombers. When the attack is made to neutralize the airdrome, the efforts will be directed at all types of installations, particularly runways, parking areas, repair facilities, fuel storage, and antiaircraft batteries. When the bombing precedes a vertical envelopment, the attack is concentrated on defense installations. Bombing avoids runways and facilities necessary for use by the invading force. All visible personnel are systematically machine gunned from low-flying airplanes. The attackers strafe the edges of woods and all other obvious hiding places.

149. Airborne attack.—*a.* Airborne troops include parachute troops and air landing troops. Air landing troops may be transported in powered aircraft or in gliders towed behind aircraft.

b. The aircraft which carry parachute troops usually fly in a V-formation of three or four airplanes. During the jumping period the airplanes travel slowly at an altitude of from 200 to 400 feet. A platoon of trained men can land in an area 250 by 600 yards, a battalion in an area 700 by 1,000 yards. Time of descent from airplane to ground is from 10 to 25 seconds. At the time of descent, parachute troops are equipped with light weapons such as pistols, carbines, submachine guns, and grenades. Additional light weapons, ammunition, mortars, and food are dropped by separate parachutes, each of which may be a different color. Upon landing, parachute troops will attempt to organize and gather weapons. *They are extremely vulnerable during this period of organization on the ground.* Time required for a unit to form for action averages about 10 minutes, but well-trained troops in favorable terrain will not require so much time. Assembled units on the ground will immediately start after preassigned objectives. Some will move as outposts to block roads and cut communications while others move against important terrain features, fortifications, or ground installations.

c. Air landing troops require more favorable terrain to land in than do parachute troops. They attempt to find cleared areas near the airdromes—open meadows, river beds, or straight stretches of highway—but they can crash land in very rough terrain. Gliders and air transports can carry much heavier equipment than parachute troops. They may have light field artillery pieces, antitank guns, antiaircraft guns, light transportation, small tanks, and light equipment for the construction of suitable landing areas. Air landing troops require time to unload their equipment. *They are most vulnerable during the unloading and reorganizing period.*

d. Parachute troops and air landing troops may be used separately or together, with either group preceding, in an attack. Normally the parachute troops land first as an advance guard to clear the way and to prepare areas for landing by gliders and air transports.

150. Ground attack.—Although airborne attacks may be isolated operations they are normally made in conjunction with a mechanized ground thrust or a movement across water in the case of an island base. The defense of an airdrome against ground attack involves the same principles as defense of similar terrain without an airdrome.

151. Flexible and mobile defense.—*a.* In a typical attempt to seize an airdrome, the first enemy move may be to land a few parachute troops as raiding parties the night preceding the attack. These raiding parties cut communications and do as much damage as they can to ground installations. At dawn there may be an intense air bombardment to neutralize defensive positions. Low-flying airplanes assist with ground strafing. During the air attack, parachute troops land off the airdrome in areas free from defending troops or cleared by the air attack. The air attack continues to support the efforts of parachute troops to organize, attack objectives, and clear the way for air landing troops. Air landing troops broaden and deepen the combat area established by parachute troops. All attacking troops will have accurate maps and knowledge of all fortifications and installations which have not been well camouflaged.

b. To meet this type of attack it is evident that it is necessary to set up an active defense prepared for any eventuality. A defense tied down to fixed defensive position will not be successful. Highly mobile local reserves are necessary. These reserves attempt to strike the landing troops before they can organize, to prevent them from collecting their equipment, and to destroy them before they can organize. Airborne troops which have effected a landing and have organized must be attacked and destroyed before they can be further reinforced.

152. Defense plans.—*a.* The organization of a flexible and mobile defense may be the responsibility of a ground defense officer appointed by the airdrome commander. Normally the commander of the security battalion is the ground defense officer. If there is no security battalion, the commander of the engineer unit or of the

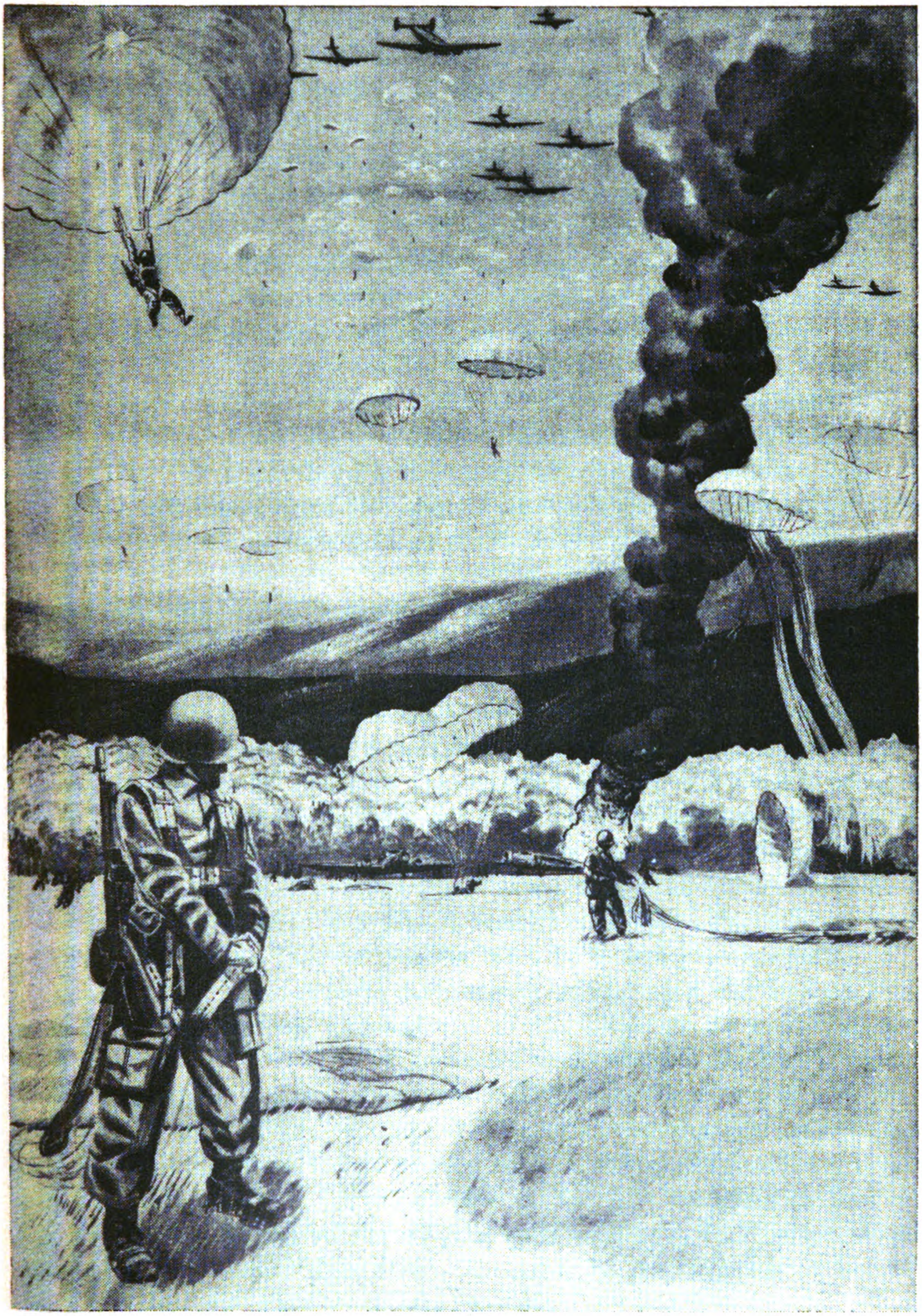

FIGURE 141.—Critical period during an attack on an airdrome.

antiaircraft unit may organize the defense. The officer designated prepares plans which are coordinated with the plans of the air defense officer.

b. Depending upon the time and personnel available, the defense plans range from general verbal instructions to an elaborate, detailed plan. In every case it covers the following points:

(1) Observation, alarm, and communication system.

(2) Camouflage and dispersion.

(3) Organization of the ground—areas to be defended, weapon emplacements, fields of fire, obstacles and obstructions.

(4) Assignment of personnel to assembly areas for combat or for shelter.

(5) Damage control.

(6) Defense against chemical attack.

(7) Immobilization of vehicles not used by defenders.

(8) Liaison with reserves and all possible supporting forces.

(9) Demolitions to prevent seizure and use of airdrome by hostile forces.

153. Alarm and observation system.—*a.* An effective alarm and observation system is the first essential in a plan for defense. The air force commander establishes an aircraft warning service in which provision is made to notify the local airdrome commander of the approach of hostile aircraft. Information of approaching attack may also be received from the antiaircraft artillery intelligence service. Sole reliance cannot be placed on the aircraft warning service, however. Sentinels must be posted to give the alarm for approaching hostile aircraft. These same sentinels can be used to warn of chemical attack and to act as spotters in case of airborne attack.

b. Observation posts should be selected so that any areas likely to be attacked are kept under continuous observation. Spotters must watch where all parachutists or air landing groups land and then direct friendly troops to these locations.

c. The alarm and observation system is useless without a communication system consisting of telephone, radio, and improvised signals. The time interval is so short in airborne attack that vehicles or foot messengers will not be satisfactory. Telephone wires must be concealed, but even then they may be cut by bombing or by troops landed to disrupt communications. Although radios are less likely to be interrupted than telephones, attackers may jam radio bands. Radio messages are usually sent in the clear. Flags, pyrotechnics, and rifle shots will be among the improvised methods of supplementing radio and telephone. Complete dependence cannot be placed on any one system of communication.

154. Camouflage and dispersion.—*a.* It is not expected that an airdrome can be completely camouflaged, but every means taken to conceal or disguise the airdrome and its installations will assist in its defense. Camouflage is covered in detail in chapter 14.

b. There is no justification for failure to disperse airplanes and ground installations. If targets for enemy bombers are spread out they will not be remunerative targets.

155. Organization of the ground.—*a. General.*—The defense of an airdrome introduces no new principles in organization of the ground. However, requirements of dispersal areas, rules regarding obstructions, forbidden magnetic areas, and other restrictions necessary for operational purposes prohibit the use of many areas tactically suitable for fortifications. Terrain surrounding the airdrome is studied carefully to determine where airborne troops can land and what avenues of approach are open to attacking ground forces. The ground is then organized to deny probable landing areas and routes of approach. This is accomplished by fire from fixed defended localities, by obstacles, and by the use of mobile striking parties. *Organization of the ground must leave the bulk of the troops away from probable bombing targets and located where they are free to meet situations as they arise.*

b. Fixed defended localities.—(1) Although the defense must not be static, at nearly every airdrome there are certain vital areas which should be kept under fire to deny their use by the enemy. In rough country which offers no suitable landing areas other than the existing runways, most of the defenders are situated to protect the runways. In more open terrain they must cover other possible landing areas; where there are many possible landing areas, the bulk of the defending troops are kept mobile. In every situation the commander of the defending forces must evaluate the terrain to determine whether or not commanding ground is so vital that it should be held by fixed defensive localities.

(2) These defended localities fall into two classes: those on the airdrome proper and those outside the airdrome. Under no circumstances is a ring of fortifications placed around the perimeter of the airdrome. Those within the airdrome are usually the more strongly defended. The positions are wired in, permit all around fire, and are supplied with reserve ammunition, water, and food. They consist of well-concealed entrenchments and open weapon emplacements, and, if time and materials permit, simple pillboxes. The size of the garrison is the minimum consistent with the fire power needed. The defended localities off the airdrome normally are not designed for

permanent occupancy. The garrison must be free to leave the defenses to attack enemy troops who have landed in the vicinity but who cannot be brought under fire from the fortified position. A skeleton garrison may be left to man the defenses while the others are attacking.

c. Need for concealment.—All weapons emplacements and defended areas must be well concealed. Preliminary bombing and strafing will neutralize or destroy poorly camouflaged positions. In addition, the attackers, who will find it difficult to organize under any circumstances, will be even more severely handicapped if they do not know where the defenders are. Particular care should be taken to conceal protective and tactical wire. It should blend with the pattern of hedgerows, fence lines, and natural growth.

d. Fields of fire.—(1) Since few of the airdrome defenses are fixed there will seldom be need for extensive clearing of fields of fire. Clearing must not give away positions.

(2) Fire must be coordinated so that friendly troops do not fire into one another. With the situation changing as rapidly as it does during an airborne attack, only careful planning can prevent cross fire of friendly troops.

e. Antiaircraft artillery.—Antiaircraft artillery is located some distance from the airdrome. All antiaircraft weapons are sited to fire at ground targets as well as air targets and must be protected from surprise attack.

f. Obstacles.—Obstacles are used to block the movements of ground troops and to prevent the landing of aircraft.

(1) Enemy ground troops may consist of armored or motorized forces which have made a break-through or they may be airborne troops which have landed and organized. A barrier system against armored and motor vehicles should be planned in advance. Obstacles consist of the normal type of demolitions, road blocks, and mine fields. Attacking foot troops are impeded with booby traps, barbed wire, and any natural obstacles which can be used to restrict the available avenues of approach. Planning and execution of such barriers and obstacles is covered in FM 5-30.

(2) Obstacles placed to prevent the landing of aircraft are called obstructions. Plans may call for blocking all suitable landing areas in the vicinity of the airdrome since enemy troops will attempt to land off the airdrome and then organize to attack it. Plans may also call for placing movable or temporary blocks on runways and landing areas normally used by friendly aircraft. Examples of movable obstacles are vehicles, heavy construction equipment, logs, rock-filled drums, and wire. However, permanent rather than temporary obstructions

should be placed in areas which are not used by friendly aircraft. Since enemy airborne troops are used to clear landing areas for hostile airplanes, obstructions must be difficult to remove.

(3) Types of relatively permanent obstructions are cables, firmly anchored timber or steel posts, and ditches. Cables are easier to remove than the other types but can be placed quickly and easily concealed. Rows of posts are effective obstructions but require considerable time to place. Although the aviation battalion has no machine for digging postholes, the ditching machine is an effective expedient. Ditches can be constructed rapidly with battalion equipment. The ditching machine followed by a grader, for example, can cut V-ditches which will stop wheeled aircraft. When time permits, the spoil should be removed so that it will not be available for filling the ditches.

(4) Camouflage requirements may considerably limit the extent of obstruction plans. In inhabited rural areas, cables may be placed to resemble fence lines, ditches may imitate drainage lines, and posts may be tied in with natural cover and obstructions; but in areas where an airdrome is successfully concealed or disguised, artificial obstructions may be so revealing that it is better to leave only natural obstructions in the surrounding areas. If the location of the airdrome cannot be concealed, the extent of obstructions is limited only by time and materials.

156. Assembly areas.—All personnel keep gas masks, weapons, and ammunition close at hand. When the alarm sounds they will report to previously designated assembly areas, armed and ready for combat.

157. Damage control.—The airdrome cannot continue to operate under attack unless vital installations and equipment are protected during attack. Dispersion and protective construction are passive means of damage control, but they are not sufficient. Crews must be organized to control and repair damage as it occurs. Detailed fire plans and efficient fire fighting squads are necessary for action against incendiaries. Crews must also be organized for repair of runways (see ch. 11) and the maintenance of communications.

158. Immobilization of vehicles and equipment.—Attacking airborne troops attempt to capture vehicles and equipment and convert them to their own use. Plans should therefore make for quick immobilization of all vehicles not needed by the defenders. Common methods of immobilization include removing keys and the distributor and ripping out essential wiring.

159. Plans for liaison with supporting units.—Defense plans should be coordinated with those of all general reserves which may be called in to assist in defense. These units should be familiar with the organization of the ground *before* they are called in as reserves. For example, range data cards may be made for field artillery whether the artillery pieces are in local defense or reserve.

160. Demolition of the airdrome.—*a.* The complete demolition of an airdrome is a major operation which requires considerable time and a tremendous quantity of explosives. It is easier to build an airdrome than it is to destroy it. The decision to prepare an airdrome for destruction is made by the commander concerned, but his decision should be anticipated by the engineer commander. The engineer should plan for demolitions from the beginning of construction.

b. Time may prohibit complete demolition of an airdrome. The following list suggests priorities and personnel for demolition:

(1) Runways and taxiways—aviation engineers.

(2) Balance of landing area—aviation engineers.

(3) Routes of communication to the airdrome—engineers.

(4) Construction equipment at the airdrome—aviation engineers.

(5) Technical buildings—air force ground troops with engineer help.

(6) Supplies of gasoline, oil, and bombs—air force ground troops.

(7) Motor vehicles and unserviceable aircraft—air force ground troops.

(8) Housing—air force ground troops with engineer help.

c. Runways present the most difficult problem. To assist in destruction of the runway by cratering, explosives can be placed in all drainage culverts. If the demolition planning starts prior to construction, additional culverts can be placed in all fills. This involves little extra work during construction and provides a means of placing explosives under the runway. A rope should be run through the culverts when they are first placed to allow bangalore torpedoes or other forms of charges to be drawn through. Culverts should be of simple wood box or tile construction, may be placed about 3 feet deep, and should have inside dimensions of about 6 inches on a side.

d. Although an airdrome has been abandoned, friendly artillery may still be within range of the site. Since an airdrome is usually an easy target on which to register, artillery fire may prevent the enemy's using the airdrome.

e. If there are a few hours available for destruction of an airdrome after it has been abandoned by friendly aircraft, the landing field may be destroyed with aviation engineer equipment. Provided the runways are not concrete, a rooter and a bulldozer can cut wide, deep lanes across any suitable landing areas. Booby traps planted in damaged areas, underneath dirt and tied to obstructions, will slow up rehabilitation efforts.

CHAPTER 14

AIRDROME CAMOUFLAGE

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SECTION I

GENERAL

	Paragraph
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161. Scope.—This chapter covers certain phases of airdrome camouflage particularly applicable to aviation engineers. It is supplementary to the material contained in TM 5-266. For a comprehensive coverage of camouflage see FM 5-20. Detailed information on camouflage materials is contained in TM 5-269. This chapter contains technical data not found elsewhere and the methods of employment of camouflage personnel.

162. Films.—The following films are available for camouflage instruction: TF 5-648, TF 5-649, TF 5-646, and an Engineer Board film on pierced plank runway mat which covers many camouflage expedients.

163. Definition.—Camouflage is protective concealment; it includes means of hiding or disguising yourself from the enemy; of misleading him as to your position, strength, and intention, and of confusing him so that he wastes his blows.

164. Value and purpose.—*a.* Airdromes are generally beyond the range of hostile artillery fire. Defense of airdromes is primarily against aerial attack. Camouflage as a means of decreasing the effectiveness of aerial attack is an important weapon of defense.

b. Although airdrome camouflage attempts to hide or disguise the airdrome from the aerial observer, it is to be expected that the enemy will be able to learn the general location of the airdrome through careful study of aerial photos, observation of normal unavoidable activities, and through intelligence reports. However, successful precision bombing can be accomplished only when the target is clearly visible in the bomb sight. In most instances it is not the intent of camouflage to conceal airdromes completely but to reduce their visibility to a point where the enemy bombardier will have difficulty in obtaining a clear sight from the distance necessary for successful bombing. It should be recognized that the bombardier operates under handicaps due to high speed, considerable altitude, antiaircraft fire, and fighter defense. Successful airdrome camouflage forces the enemy to approach the target at lower altitudes, take two or more runs over the target, or employ a greater number of bombers to accomplish the desired results. In these cases antiaircraft defenses have a better opportunity to inflict damage and fighter airplanes have more time to attack.

165. Airdromes as aerial targets.—Because of size, airdromes are comparatively easy targets to identify from the air. The ways in which the enemy pilot can most easily locate and definitely identify an airdrome are—

a. Landmarks in the immediately vicinity. These include characteristic coast features, lakes, mountains, towers, or highway intersections. Such landmarks, if located within a mile or two of the airfield, may become direct reference points upon which the bombardier may aim. Thus the airdrome can be successfully bombed even though it is concealed from view completely.

b. Form and bulk of an airdrome. Runways necessarily must be long and straight, and if hangars have been erected, their size alone makes camouflage difficult. Any symmetrical geometric pattern of roads, runways, or buildings is helpful to the enemy.

c. Shadows cast by man-made construction. Frequently these are more visible than the structure itself.

d. Texture. Texture is the degree of roughness of a surface and its ability to cast shadows within itself. For example, from the air the surface of a runway will appear lighter than the adjacent turf because light is reflected from the runway and absorbed by the turf. The runway has less texture than the turf. The heavier or taller the growth of natural foliage, the deeper the texture is and the darker the appearance from the air. *Texture identifies many features of the airdrome.*

e. Color is usually the least important consideration. When viewed from higher altitudes colors tend to lose their identity to a considerable degree.

f. Night lighting of runway or bivouac area which may identify the airdromes.

166. General methods of camouflage.—The following general classifications cover the methods by which airdromes are camouflaged:

a. Darkening, or "toning down."—This generally involves painting or texturing all highly reflective surfaces, such as concrete runways and buildings.

b. Deception.—This involves changing the identity of the installation to make it appear from the air as something other than an airdrome. For example, an airdrome with a hangar might be treated to represent a farm surrounded by plowed fields and pastureland. Figure 142 shows one detail of an effort to change the identity of an airdrome.

c. Decoys.—Decoy installations are used to advantage to distract the attention of enemy bombers. One or more decoys located at a suitable distance from the airdrome may effectively conceal it by focusing all attention on the false installation. Figure 143 shows an entire decoy field. Figure 144 illustrates a typical decoy. Other decoys are shown in figures 168 and 169.

d. Complete concealment.—Instead of merely reducing the visibility of installations, an attempt may be made to conceal them completely. Ground patterns of the surrounding terrain may be extended over runways, nets may be erected on visible buildings, and flat-tops may be placed over parked aircraft. A partial attempt at complete concealment is shown in figure 145.

167. Site selection and lay-out.—Chapter 5 covers the details of site selection. The engineer who assists in site selection should give camouflage full consideration in selecting a site and in making the preliminary lay-out of the installations.

a. Dispersion.—Although dispersion increases the difficulties of communications and servicing, it is essential to allow for it in site selection. Dispersion permits the best use of the existing ground pattern and natural concealment and reduces the damage caused by bombing. (See figs. 44 to 51, incl.)

b. Landmarks.—Properly chosen location for an airdrome will not be in the immediate vicinity of any prominent landmarks, converging roads and railroads, or other points which can be used as reference points by enemy bombers (see par. 165*a*).

c. Undesirable terrain.—Where possible, sites with uniform tone and texture should be avoided. Woods are ideal for concealing buildings, equipment, and personnel, but the slashes made by runways offset the advantage gained by concealing smaller installations. Runways in a broad expanse of grassland are just as obvious.

d. Desirable terrain.—The ideal terrain for an airdrome contains a variety of patterns. An area of woods, brush, grassland, and fields of varied crops aids concealment. One more change of texture is not evident and a properly executed camouflage plan can retain the broken pattern.

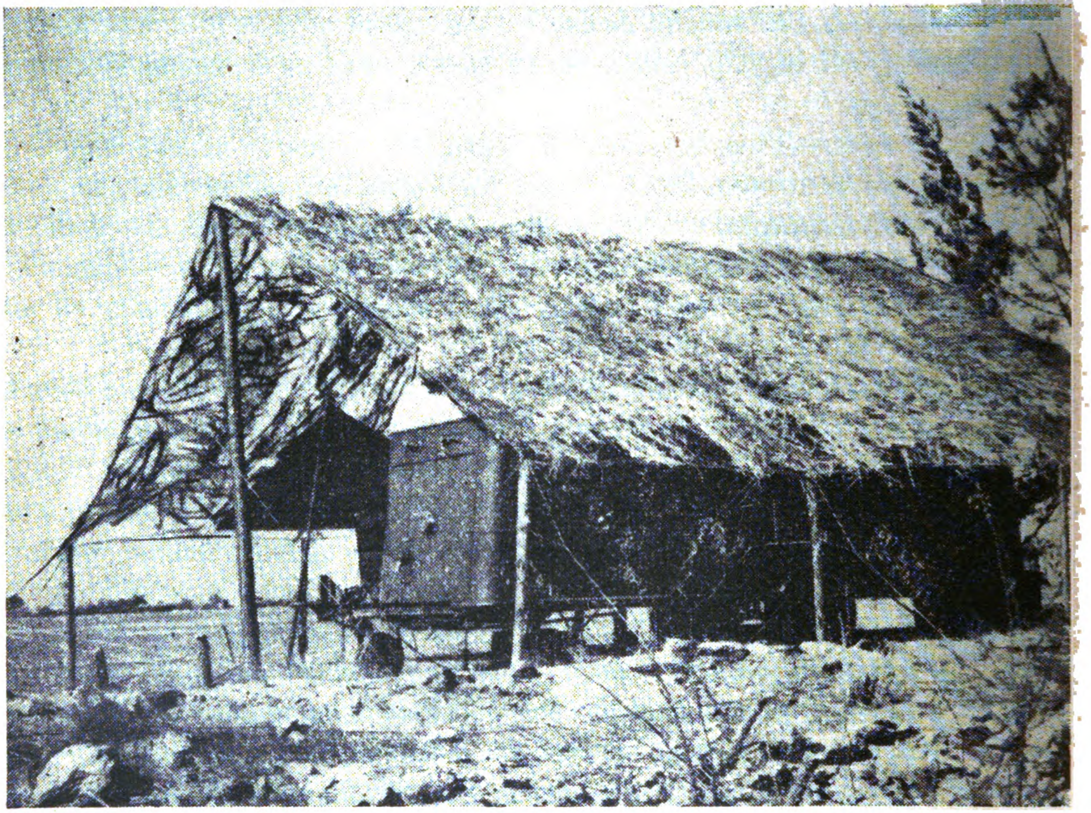


FIGURE 142.—Press trailer treated to resemble barn from the air. Note large proportion of local materials used.

e. Irregularity of lay-out.—Straight roads and straight rows of buildings and hangars are to be avoided. Since there are no straight lines and no geometric shapes in nature, such lay-outs automatically catch the eye of the enemy bombardier.

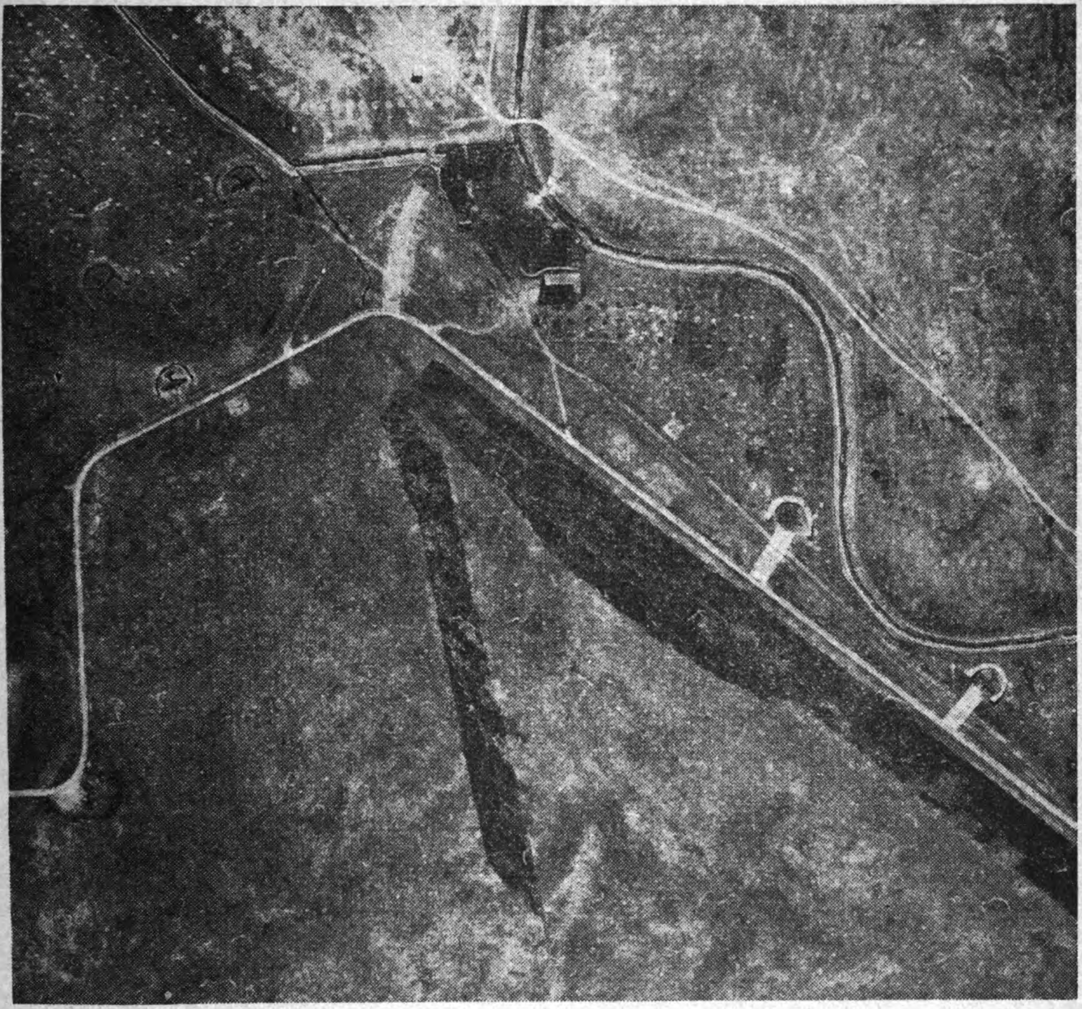


FIGURE 143.—Decoy airfield under construction.

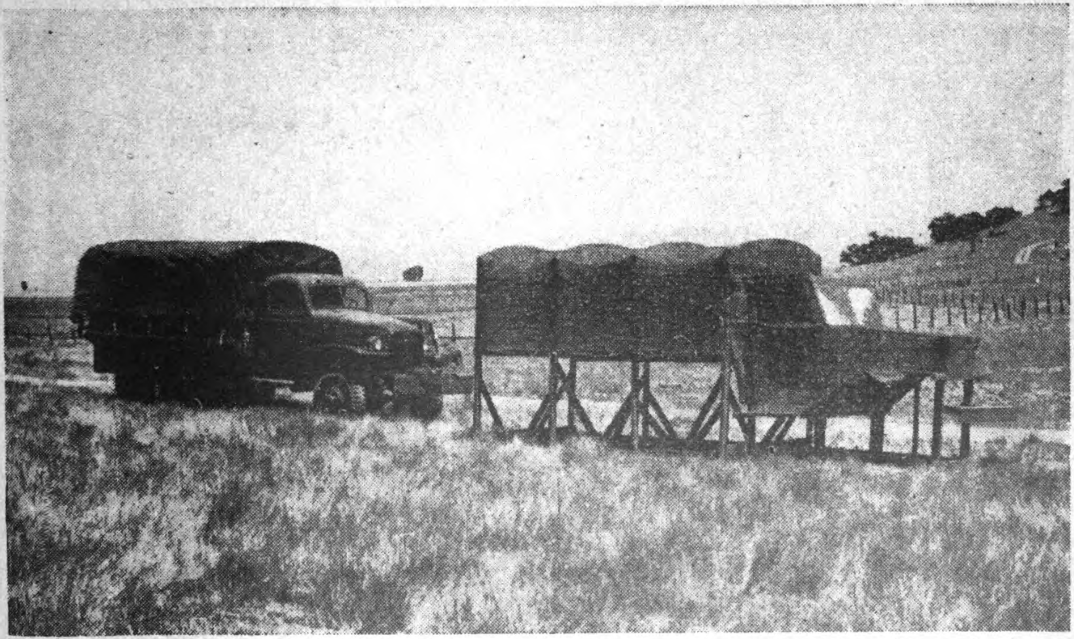
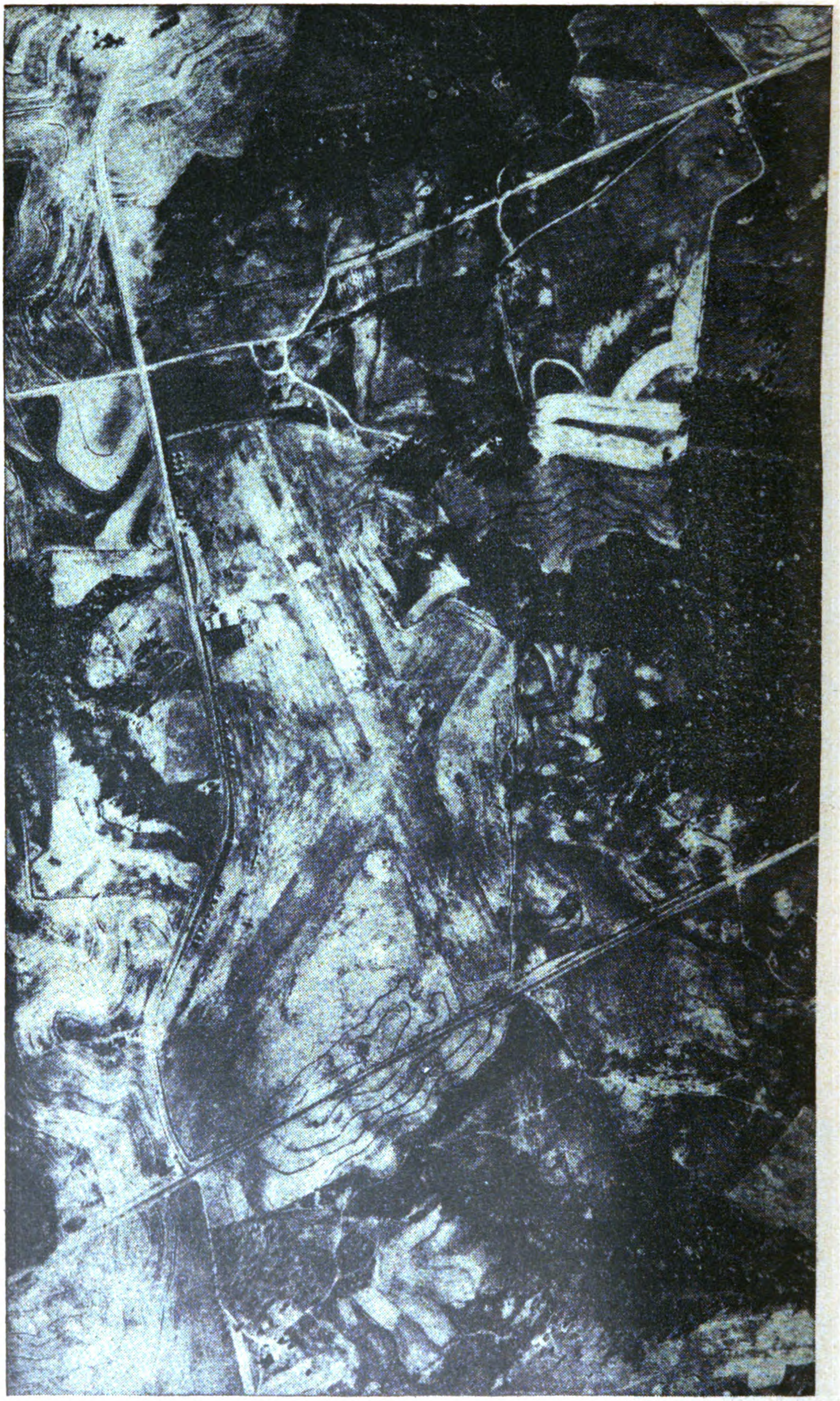
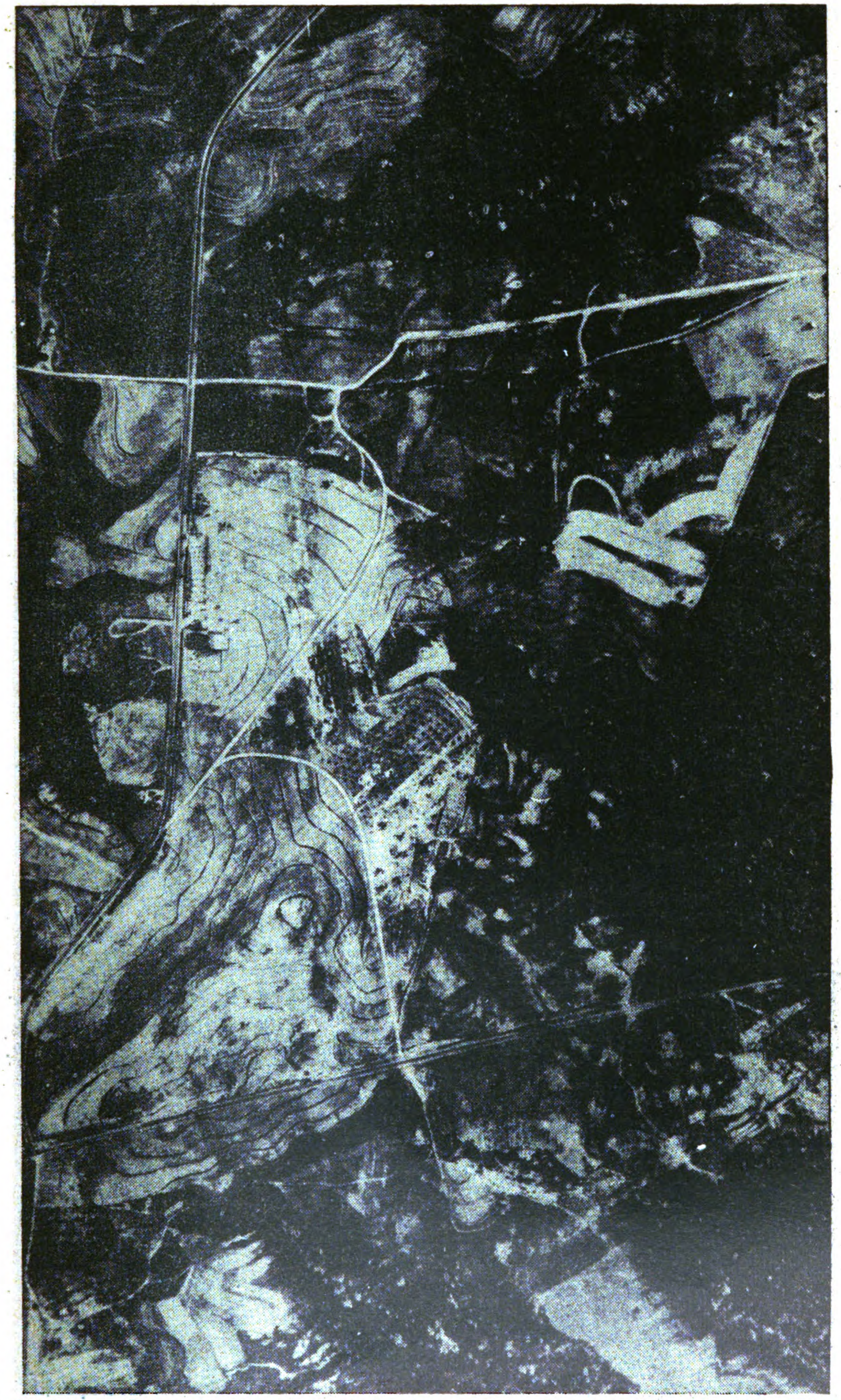


FIGURE 144.—Decoy truck. Although not of themselves important targets, such shams add realism to decoy airdromes and other false installations.



① Airdrome before camouflage. Note characteristic appearance of adjacent fields due to contour plowing.

FIGUERE 145.



② Airdrome after camouflage. Typical contours have been carried over the runways; dummy roads and an orchard have been added.

FIGURE 145—Continued.

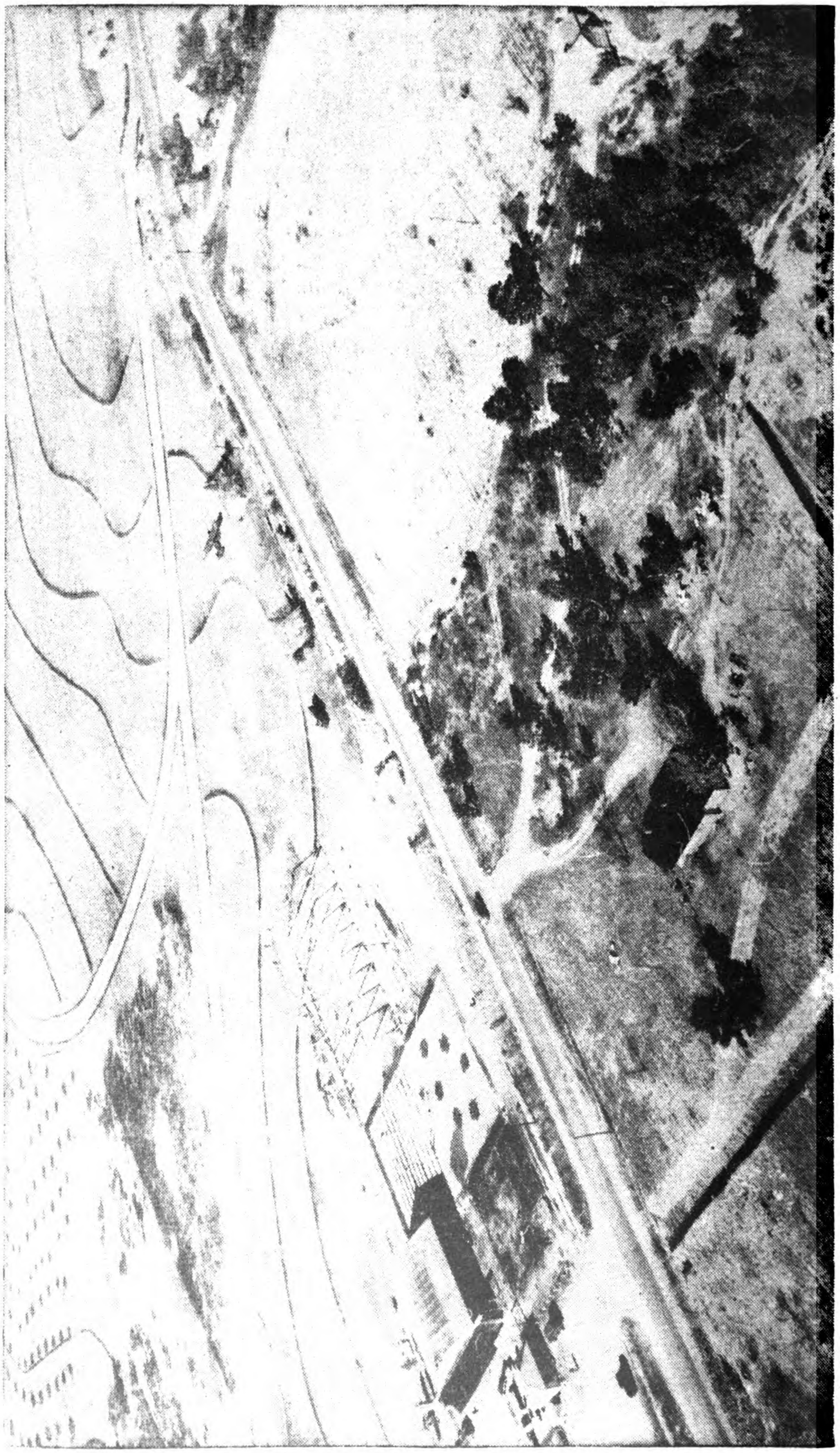


FIGURE 146.—Details of airdrome shown in figure 145. Note dummy road, painted hedges, trees, and ground contour, and dummy basin in which press trailer is hidden.

SECTION II

CONSTRUCTION AND PLANS

Paragraph
General 168
Organization of battalion camouflage section 169
Reconnaissance of selected site 170
New construction 171
Preservation of natural plant materials 172
Runways 173
Taxiways 174
Drainage 175
Lighting 176
Facilities 177

168. General.—*a.* Successful camouflage cannot be added like a coat of paint to a completed installation. Throughout the planning and construction of any new site, camouflage plans must be tied in with construction plans.

b. This section covers camouflage considerations in connection with planning for construction. Although the duties of the camouflage officer and camouflage section are treated in connection with the engineer aviation battalion, the same responsibilities apply to any officer and section charged with camouflage in connection with airdrome construction.

169. Organization of battalion camouflage section.—In the engineer aviation battalion there is one officer especially trained in camouflage. The section to assist him consists of 1 noncommissioned officer and 10 men. The camouflage officer is responsible for drawing up the camouflage plan and for its execution. His program should be carried out step by step with the construction program. The members of the section assist in handling camouflage supplies, in supervising camouflage construction, and in maintaining camouflage discipline.

170. Reconnaissance of selected site.—When the battalion commander and S-3 go forward to reconnoiter a site selected for a new airdrome, the camouflage officer goes with them to determine camouflage requirements. The camouflage plans are then coordinated with S-3. Included in the plans is a labor estimate and an estimate of camouflage materials required. The materials estimate is given to S-4.

171. New construction.—*a.* New construction should be held to a minimum. It is essential to retain the existing character and pattern of the surroundings in the development of a new site. The less interference with the pattern and features of the ground the better the concealment. Where disturbance is unavoidable, ground scars should be confined to construction areas as far as possible. Any changes and additions should be designed to blend, not contrast, with general surroundings.

b. Only that portion of the area required should be altered or developed in any way. New roads, runways, taxiways, and ditches should be located along existing ground lines; roads should be planned to lead to some logical destination. Existing roads, trails, and fence lines should be incorporated into the new lay-out as lines of communication. Existing buildings are utilized where possible.

172. Preservation of natural plant materials.—There are few more effective methods of screening such features as buildings and roads (fig. 147), dispersed aircraft (fig. 148), and communications than by the use of trees, shrubbery, and other plant materials. They should be removed only where actual construction makes it necessary. All clearing and topping of trees should be done along irregular lines except where the existing ground pattern indicates otherwise. For best results, the limitations of clearing and the location of useful trees and tree masses should be noted on the ground plan to insure their preservation when laying out the buildings, runways, and other units.

173. Runways.—*a.* Criteria for runway lay-out and dimensions are given in chapters 5 and 6. However, the position and type of runway should not be determined solely by ease of technical construction. Both technical and camouflage aspects should be considered.

b. In spite of limitations as to size and direction of runways, there are usually several possible locations for any particular runway. Time spent in determining the best location may be made up by ease of camouflage of that location. Clearing is normally required adjacent to runway areas but such clearing should be held to the minimum necessary for operation. Low trees, scrub growth, and shrubbery frequently can be left.

c. The common types of runways in order of increasing difficulty of concealment are—

All-over turf fields.
Sodded runways.
Open mesh steel runways.
Stabilized soil runways.

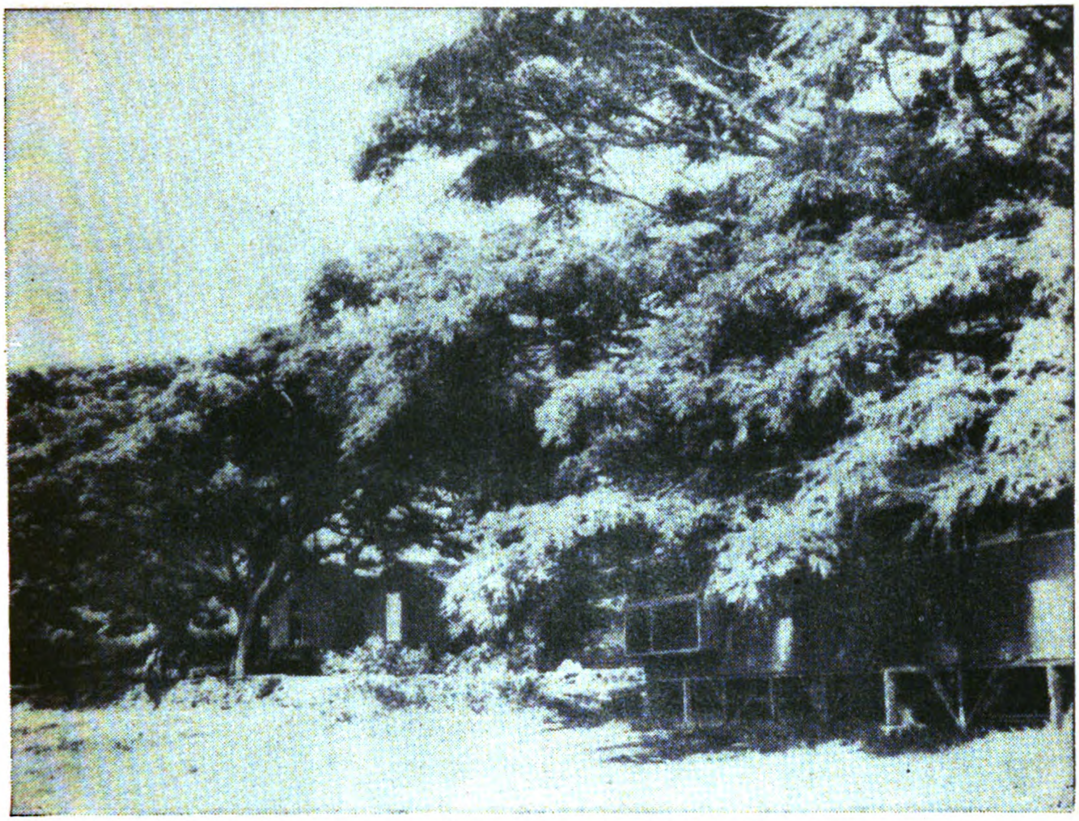


FIGURE 147.—Natural camouflage. Utilization of existing foliage for concealment eliminates need for extensive artificial camouflage.

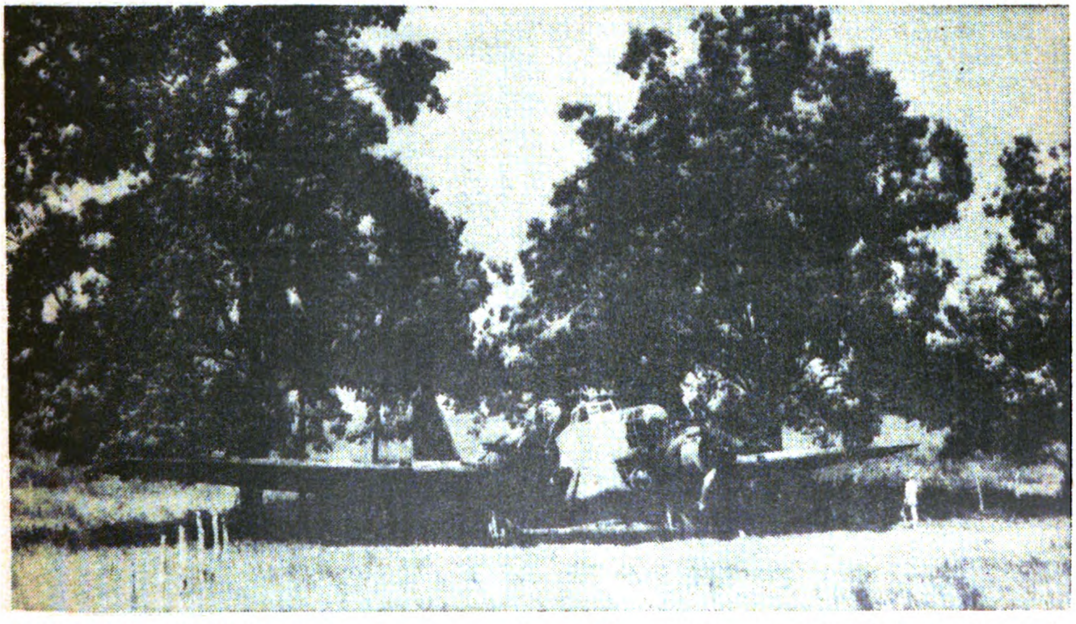


FIGURE 148.—B-18 located under trees. Very little supplementary work is necessary to hide this airplane from aerial observation.

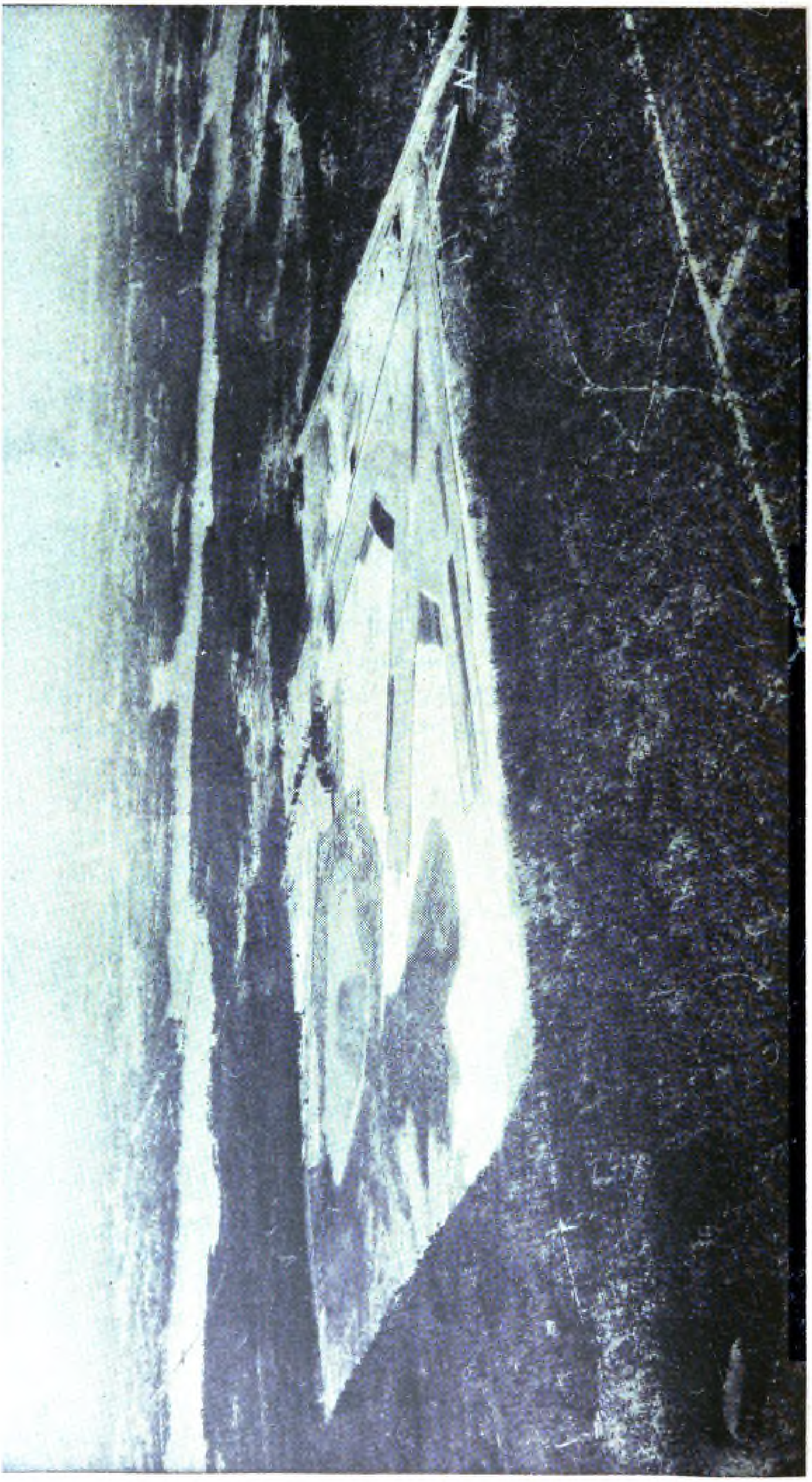
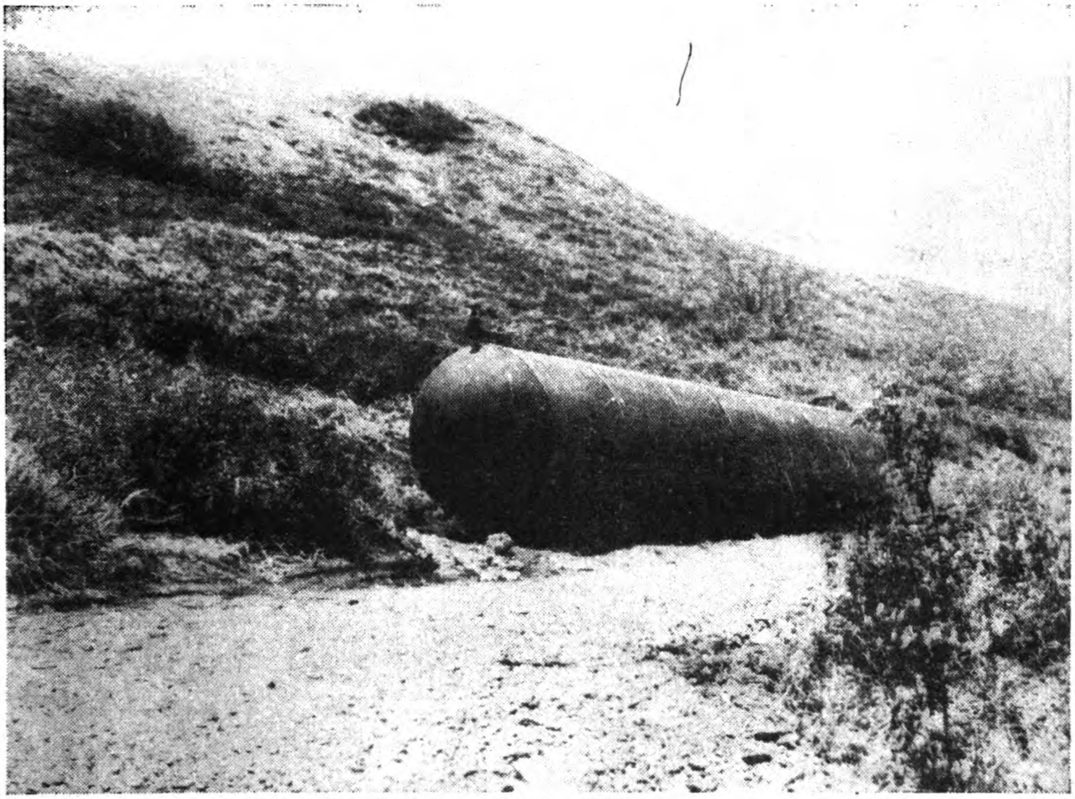
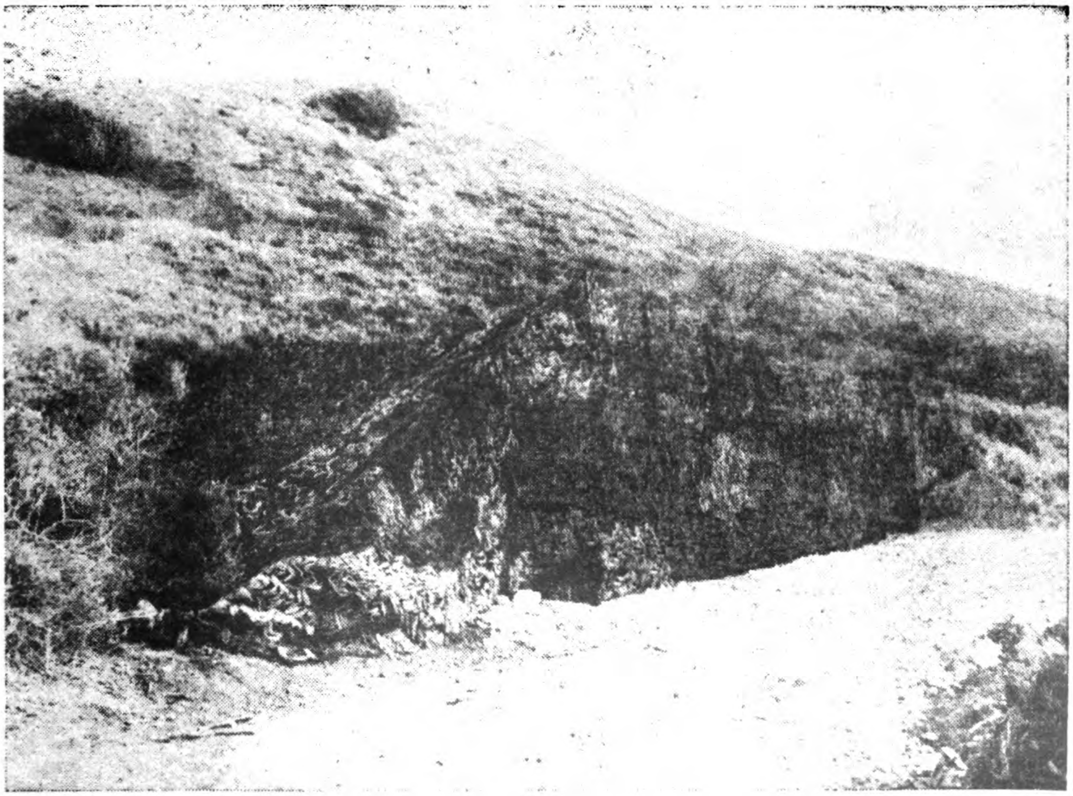


FIGURE 149.—No attempt has been made to preserve natural materials and clearing has been done along straight lines.



①



②

Figure 150.—Use of a garnished net drape to conceal a gasoline tank whose shadow otherwise would be very conspicuous from the air. Tank would be situated under cover if cover existed.

Bituminous runways.

Concrete runways (not topped with bitumen).

No matter what surface is used, its finish should generally be dark colored and rough textured. An exception to this is in an area of light colored sand.

174. Taxiways.—Taxiway design is similar to runway design. Existing roads can often be converted into taxiways and new taxiway construction should follow the pattern of established roads.

175. Drainage.—Open V-type ditches are used to drain most runways. For camouflage purposes they should be as irregular in lay-out as possible and should have gently sloping sides. Sod, grass, vines, and other fast-growing plant materials assist concealment of ditches.

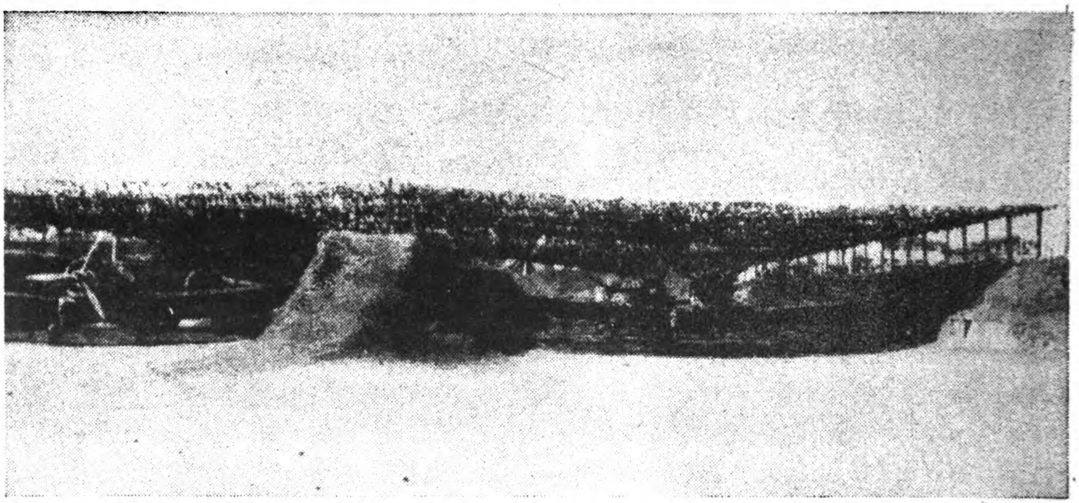


FIGURE 151.—Use of large flat-top to conceal airplanes in revetment where natural cover does not exist.

176. Lighting.—Night lighting installations should not obviously reveal the extent and location of the runway areas. Portable lighting sets (see ch. 6) have dimmed, shielded lights which are visible only from certain altitudes and angles of approach.

177. Facilities.—The facilities for housing, servicing, and supply must be as well concealed as the runways, taxiways, and drainage system. Existing buildings should be utilized wherever possible, even to the extent of moving them to the new location. Where new construction is required, the size, shape, color, and materials should conform to those of surrounding areas. Nets, drapes, and artificial garnish must be used where cover is insufficient (figs. 150, 151, and 152).

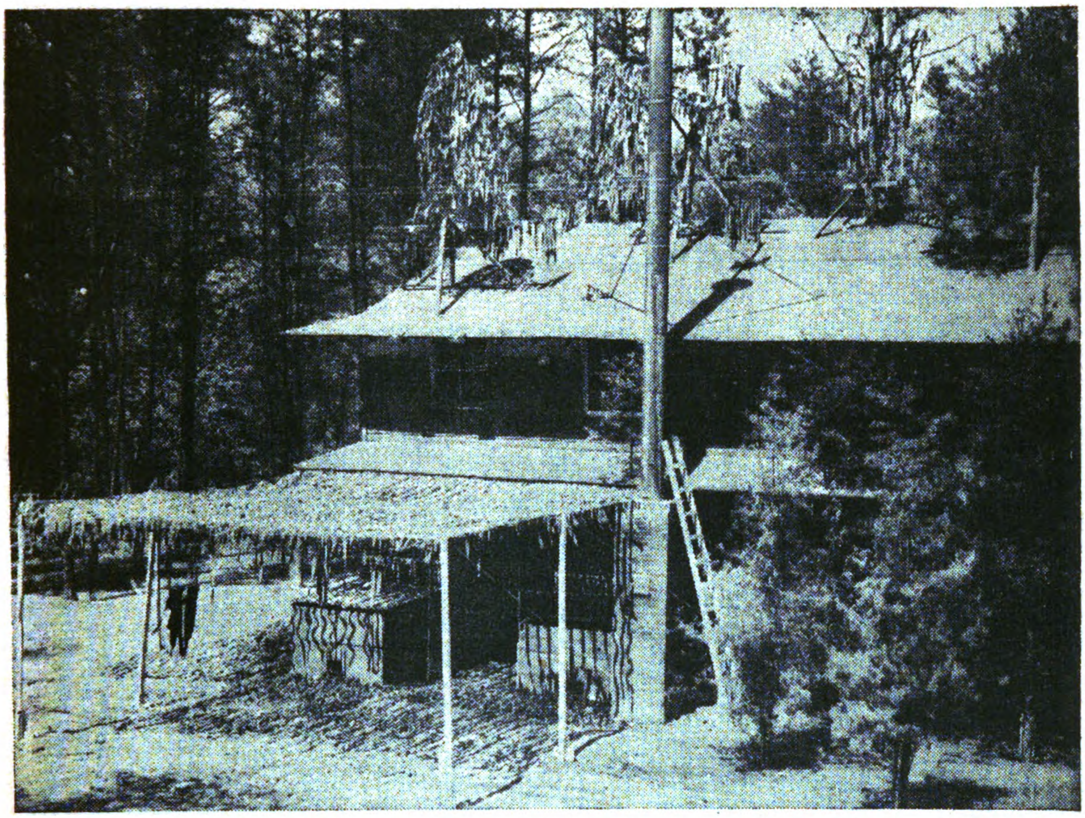


FIGURE 152.—Although building has been sited under cover, nets and artificial trees are used to help break up form and shadows.

SECTION III

DISCIPLINE BEFORE AND DURING CONSTRUCTION

Paragraph
Moving into bivouac ---- 178
Difficulty of task ---- 179
Camouflage on the job ---- 180
Concealment of equipment during raids ---- 181
Units occupying airdrome ---- 182

178. Moving into bivouac.—*a.* From the time the first man or vehicle arrives at a construction site, the camouflage section is responsible for maintaining camouflage discipline and for supervising the execution of the camouflage plan. It is necessary, therefore, that camouflage personnel be present when the advance party goes forward to lay out a bivouac area for the construction crew. Before the main body arrives, the area should be set up to preserve the natural features of the site which assist in concealment.

b. The camouflage officer makes up a complete traffic control plan which is submitted to S-3 for approval. Men and vehicles are moved over predetermined, covered routes. Traffic guards guide traffic along the proper roads; roads and paths are wired and taped; numerous directional and disciplinary signs such as "Keep on wired paths" are posted, and exposed areas are designated as "Off limits."

c. All areas for occupancy for men and equipment are marked off. The location of each tent, building, latrine, garbage dump, and vehicle is definitely established before the area is used.

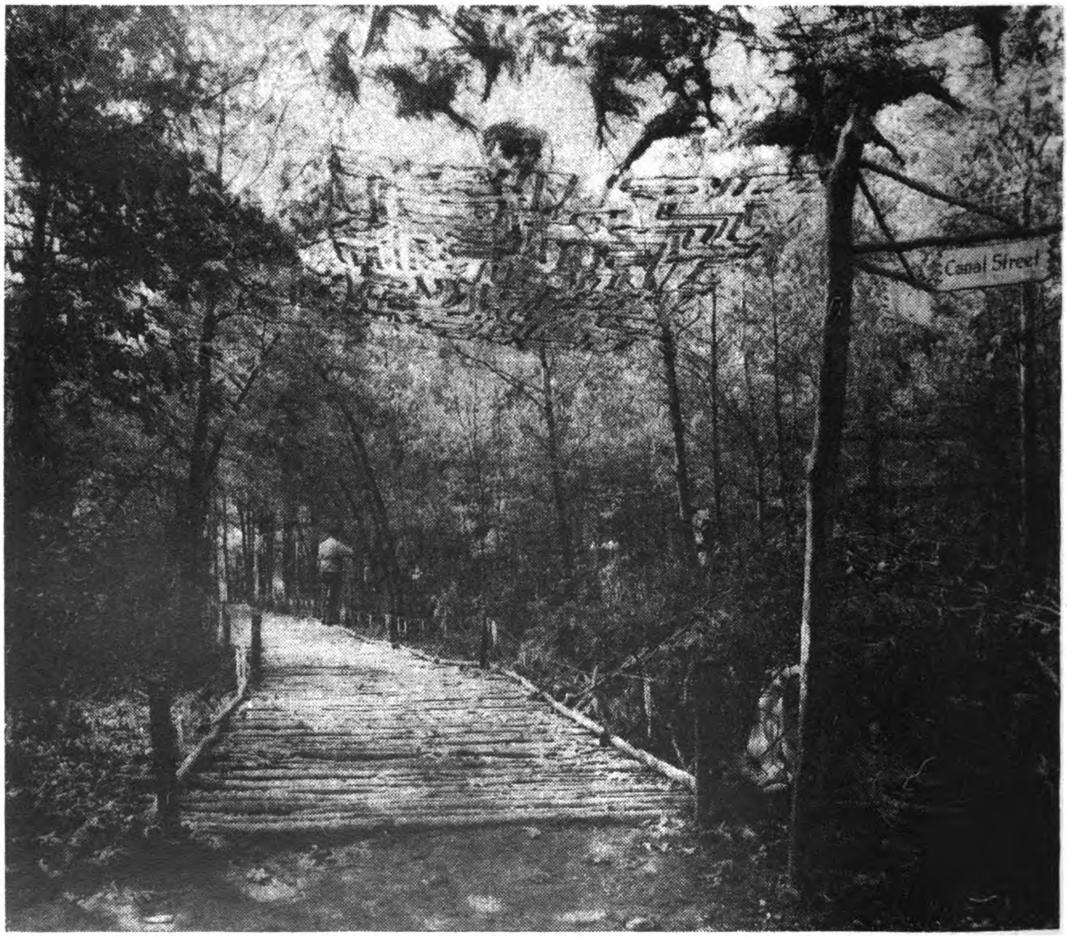


FIGURE 153.—Wired paths, constant supervision, and cooperation by all personnel constitute good camouflage discipline. Note concealed dump at the right, overhead cover for the path, and treetops wired together over open space in the background.

179. Difficulty of task.—A great deal of effort is required to maintain camouflage discipline of the bivouac area alone. It is essential work which must be performed if the site is to be concealed properly. (See fig. 153.)

180. Camouflage on the job.—Natural vegetation is retained as much as is consistent with the construction plan. Only constant supervision by the camouflage officer and his assistants will prevent violation of the plan. During the clearing operations, only marked trees and bushes are cut or topped; all others are left untouched. The movement of tractors, scrapers, and other equipment is checked continually to make sure that their operation is confined to the necessary areas.

181. Concealment of equipment during raids.—Construction equipment should be assigned dispersed parking areas under cover, to be used if an air attack occurs while the equipment is working out in the open. There will be enough time to hide the equipment if an effective air-warning service is in operation.

182. Units occupying airdrome.—Before construction is complete, tentative traffic control and camouflage discipline plans should be made for the air force units which are to occupy the airdrome. Camouflage of the engineer bivouac area and of the airdrome facilities is wasted if other troops do not carry out the same plan as soon as they occupy the airdrome. Since a completed airdrome will normally have only a small detachment of engineers, the air force units should designate responsible camouflage officers. The engineers who have developed the site should render all assistance possible prior to leaving the airdrome.

SECTION IV

MATERIALS

Paragraph
General 183
Screening materials 184
Texturing materials 185
Coloring materials 186

183. General.—*a.* An extensive variety of natural and artificial materials may be used in camouflage work. Natural materials are generally desirable because they match local color and texture, are generally available in abundant quantities, and reduce the amount of supplies needed from depots. Artificial materials are used to supplement natural materials and to conceal permanent installations. They are a necessity when natural materials are not available. (See TM 5-269 for detailed information on camouflage materials.)

b. Camouflage materials may be divided into three general types: screening, texturing, and coloring.

184. Screening materials.—Among the common screening materials are twine nets, woven paper nets, chicken wire, garnishing materials, and supporting materials.

a. Twine nets are issued in eight sizes:

12 by 12 feet
22 by 22 feet
14 by 29 feet
17 by 36 feet
20 by 60 feet
29 by 29 feet
36 by 44 feet
45 by 45 feet

Since twine nets shrink when wet and expand as they dry they must be adjusted with changes in weather. They are light, fold into a small space, and are good temporary covers for flat-tops. Shrimp nets are similar to the nets just mentioned, but have a smaller mesh and may be used as drapes for vehicles without garnishing.

b. Woven paper nets are made of waterproofed and fireproofed woven paper and are used for the same purposes as twine nets.

c. Chicken wire is issued in 6- by 150-foot rolls. It is used in a manner similar to twine and paper nets but is of a more permanent nature. Compared to a net, it can bridge a longer gap without sagging, will not shrink or expand in changing weather, and is relatively fireproof. Because of stiffness, chicken wire cannot be used as a drape but is suitable for construction.

d. Garnishing materials (fig. 147) are continually being developed. The most common types are as follows:

(1) *Osnaburg*, a low cost cotton fabric similar to heavy unbleached muslin. It is usually issued in packages of 10 rolls, each roll being 2 inches wide and 100 yards long. The cloth as issued may be white (unpainted) or it may be painted in any of the standard camouflage colors. Although normally issued in convenient strip size as indicated above, osnaburg may also be issued in bales about 1,000 yards long and either 30 or 40 inches wide.

(2) *Burlap*, issued in the same sizes and colors as osnaburg, and generally similar to it for camouflage purposes.

(3) *Steel wool wire netting* (fig. 154), made of steel wool mounted on chicken wire or welded web wire. It is issued in 6- by 75-foot rolls, takes paint readily, and has excellent texture.

(4) *Vegetable fibers* such as tula, seaweed, kelp, thatch, and Spanish moss are treated vegetable growths used in localities where they are plentiful.

(5) *Chicken feathers* fastened to chicken wire with an adhesive are an excellent garnishing expedient (fig. 155).

FIGURE 154.—Center section illustrates chicken wire garnished with osnaburg. Net on left is steel wool. Net on right is experimental metal net.

e. Supporting materials such as stakes and wire are necessities for supporting many camouflage structures. Stakes are usually of natural materials of suitable diameter cut into lengths desired. For permanent installations, finished lumber or steel tubes may be used. The most common sizes of wire are No. 10 and No. 16. Both sizes are issued in 100-pound rolls. The No. 10 roll is about 2,000 feet long, while the No. 16 roll is 9,800 feet long.

185. Texturing materials.—*a. General.*—Texturing should be done with a material which can be firmly secured to the pavement with an adhesive, which will not cause skidding or ground looping, and which is available locally in quantity. Among the materials used for texturing are sawdust (large cut), chopped corncobs, cottonseed hulls, wood chips (fig. 156), and fine aggregate. Chicken feathers are used for texturing surfaces as well as for garnishing nets.

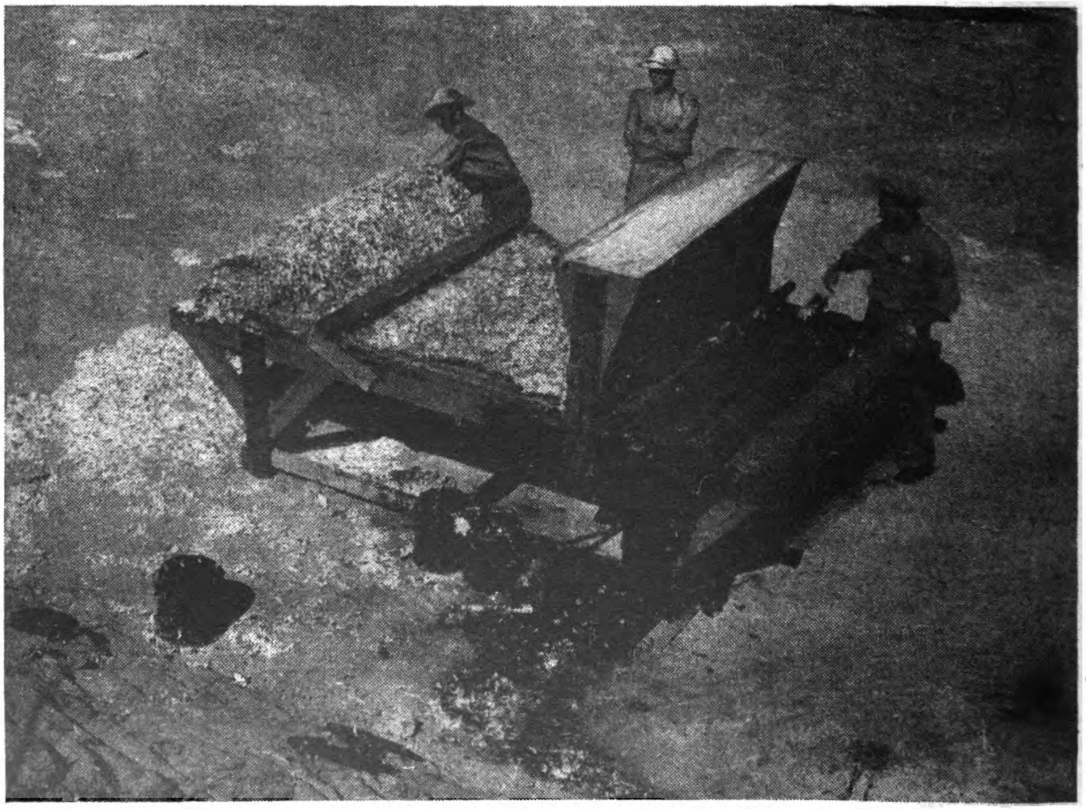
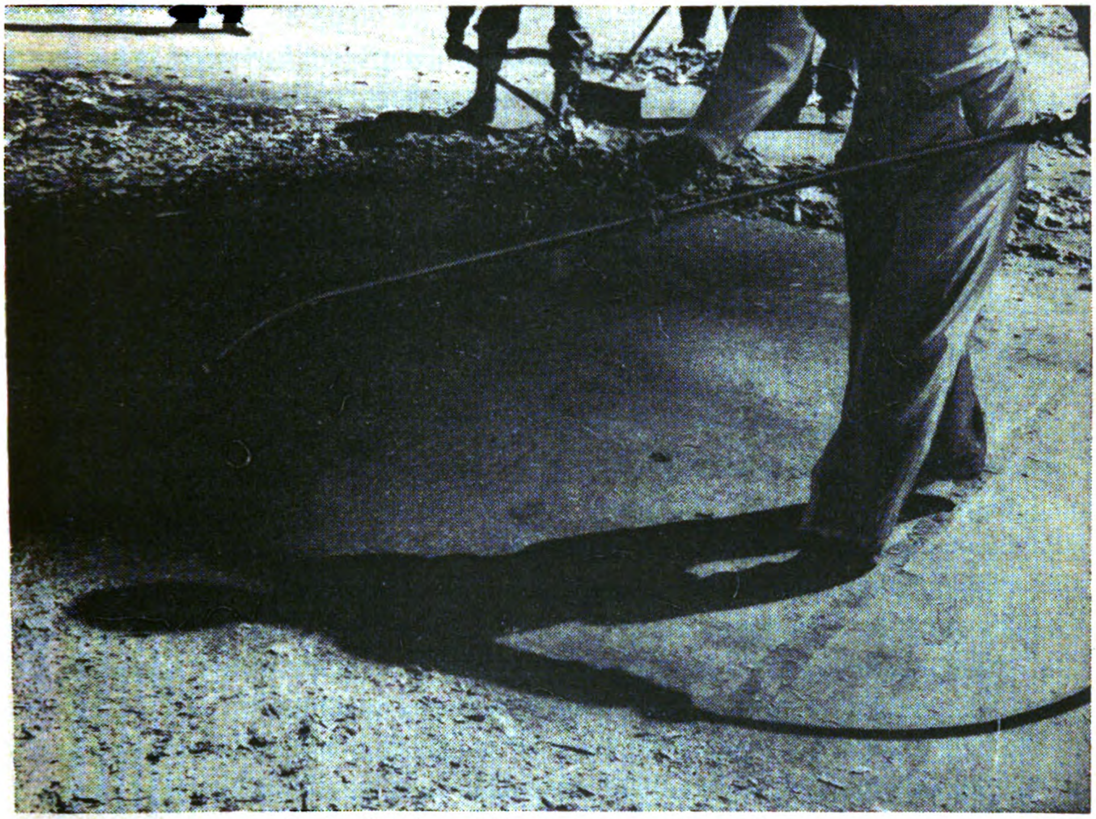
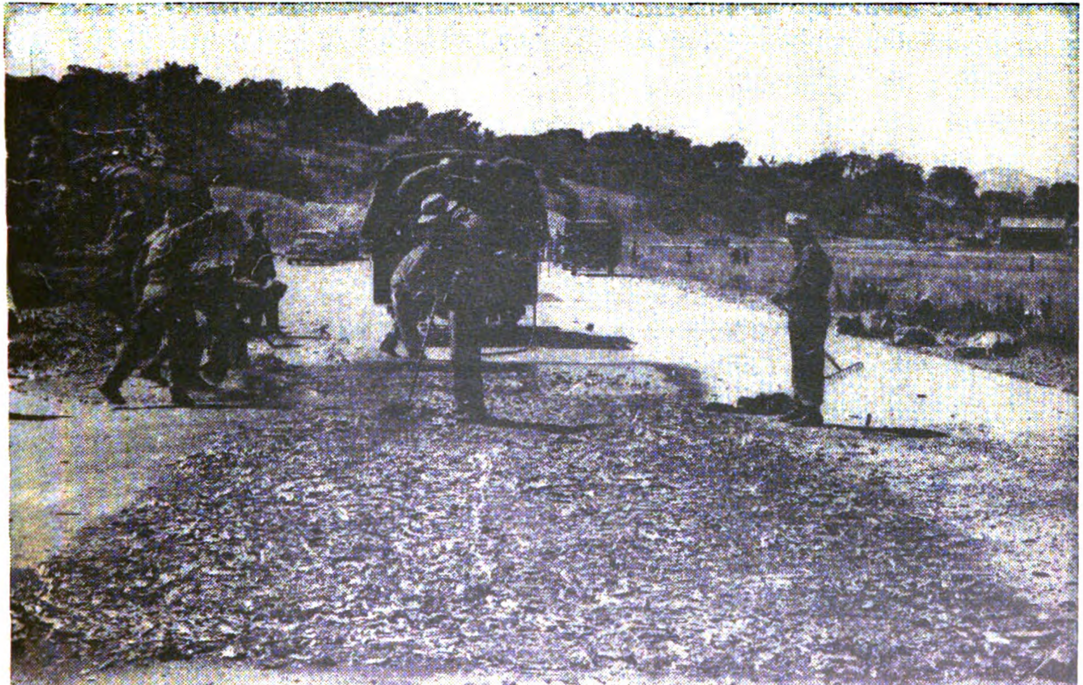


FIGURE 155.—An easily constructed device for attaching feathers to chicken wire. The result is an effective garnish.

b. Application.—Paved surfaces must ordinarily have a certain degree of texture before coloring is applied. Suitable texture may be obtained during surface course construction or by special surface treatment following pavement construction.



① Application of bitumen to serve as adhesive.



② Wood chips spread on evenly to diffuse reflection.

FIGURE 156.—Addition of texture to smooth surface by hand methods. In large areas the distributor is used to spread the bitumen.

(1) When the situation permits, texture can be provided *during construction* by either a mixed-in-place bituminous surface course using macadam aggregate (par. 122*f*) or a plant mix with a coarse graded aggregate (par. 122*h*). Variation in texture to obtain the pattern desired in different sections of the runway is obtained by varying the maximum size of coarse aggregate mixtures. Usual range of maximum size is from ½ inch to 1¼ inches.

(2) Previously constructed bituminous surfaces which do not have suitable texture may be surface treated, using the procedure for applying seal coat (par. 122*d*). The rules for good construction practice given in chapter 10 apply to camouflage work. Any of the bituminous materials listed in table XXXVI may be used for the seal, but RC's and asphalt cements applied hot are preferred. Rate of spreading seal coat must be adjusted to provide proper adhesion of texturing material. Normally the rates suggested in paragraph 122*d* are satisfactory, but for coarse texturing material a rate of 0.3 or 0.35 gallon per square yard may be necessary. Texturing material should be spread *immediately* after the bituminous seal is applied.

(3) To insure adhesion of seal and texturing material on concrete or old bituminous surfaces, it is desirable first to clean the surface by brooming, then prime it while dry with a fluid RC cut-back spread at about 0.1 gallon per square yard. Cut-back asphalt RC–O is a suitable primer if an asphaltic seal is used. If RC–O is not available any other RC cut-back may be diluted to proper fluidity with gasoline or kerosene. Creosote oil is a suitable primer if a tar seal is used. The prime coat is followed by a seal coat as in (2) above.

186. Coloring materials.—*a*. The standard camouflage colors are known by the following names and identifying numbers:

(1) Light green.
(2) Dark green.
(3) Sand.
(4) Field drab.
(5) Earth brown.
(6) Earth yellow.
(7) Loam.
(8) Earth red.
(9) Olive drab.
(10) Black.
(11) White.

b. Camouflage paints are quite different from ordinary commercial paints. They are flat and opaque and have been specially developed for easy application and recoating. The types of paints most commonly used are as follows:

(1) *Oleoresinous paint* is the best all around camouflage paint. It is issued in paste form and is stable at temperatures from −40° F. to 160° F. In temperatures above freezing it is thinned with water, while for those below freezing it may be thinned with gasoline, mineral spirts, or kerosene. The coverage for osnaburg is 250 to 300 square feet per gallon of paint which is one part by volume of paste to three parts of water or gasoline. For steel and wood its coverage is approximately 250 square feet per gallon of paint which in this case is one part paste to one part water or gasoline. Oleoresinous paint is furnished in the standard camouflage colors. It will last for about 6 months of exterior exposure.

(2) *Cold water protein paint* consists of a mixture of casein, or other type of protein, and a suitable pigment. It is issued in either powder or paste form and is reduced with water to the desired consistency. It is used principally on fabrics. One gallon of paint composed of two parts paste or powder and one part water will cover 100 to 150 square feet of osnaburg. It will usually be supplied in the standard camouflage colors, but old stocks may contain such colors as yellow ochre, burnt umber, iron oxide red, burnt sienna, and blue.

(3) *Ready mixed oil paints* are used for painting vehicles and permanent installations. They are suitable for toning down wood, brick, and steel structures. Oil paints should not be used on bituminous surfaces; this particularly applies to roofs covered with bitumen-saturated felt or paper.

(4) *Bituminous emulsions colored with pigments* can be mixed with water to the consistency desired for painting. This type of paint is relatively slow drying but is useful for toning down smooth or paved surfaces such as roofs, roads, and runways, and for painting disruptive patterns (fig. 157). It is also suitable for use as an adhesive for texturing materials.

(5) *Old crankcase oil and cut-back asphalts* may be available, but they have a limited application.

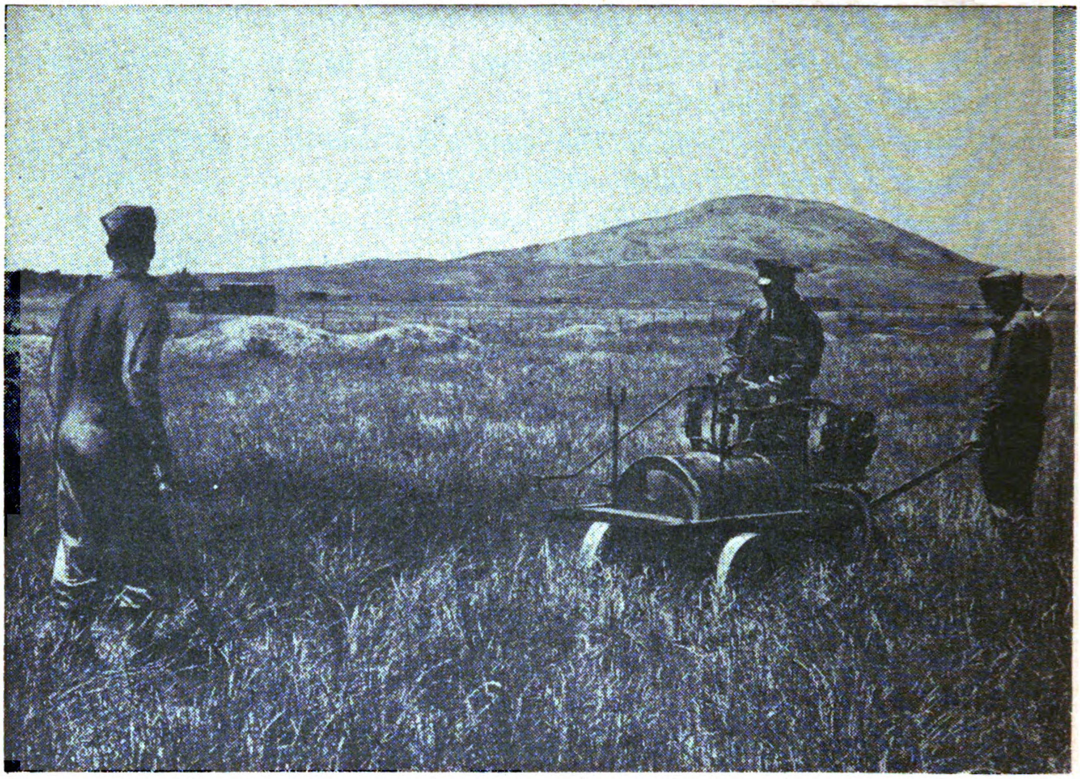


FIGURE 157.—By use of bituminous emulsion effect of tree can be created in disruptive pattern.

SECTION V

CONSTRUCTION AIDS AND EXPEDIENTS

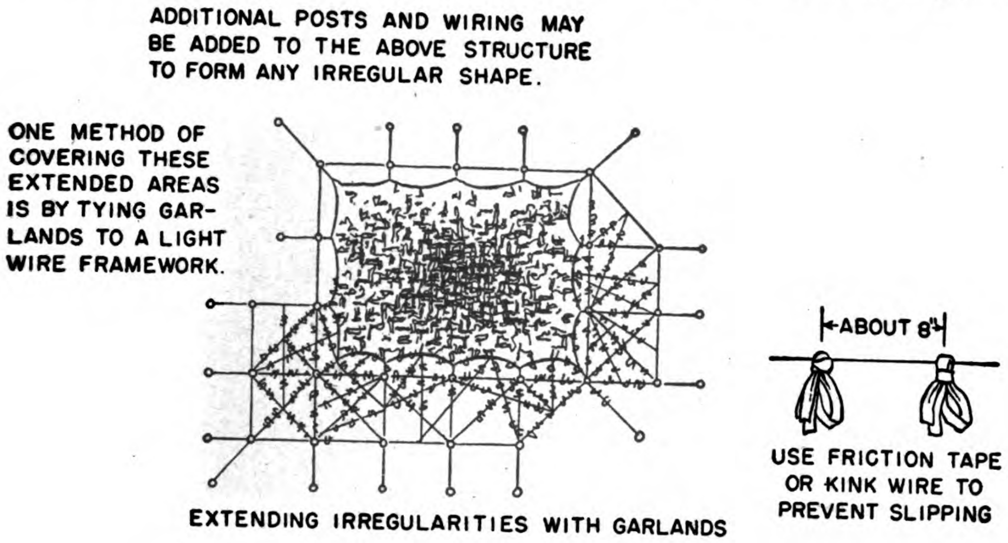
Paragraph
Erection of permanent flat-top 187
Erecton of roll-type flat-top 188
Erection of terraced flat-top 189
Erection of fly-top 190
Erection of cantilever flat-top 191
Field paint rack 192
Methods of garnishing 193
Folding nets 194
Construction of decoy airplane 195
Decoy guns 196
Construction of portable mat loom 197
Artificial rocks and trees 198

187. Erection of permanent flat-top (fig. 158).—The following method of construction lends itself to any size or shape of cover and may be used to support either a garnished net or plain chicken wire used as a base for natural material:

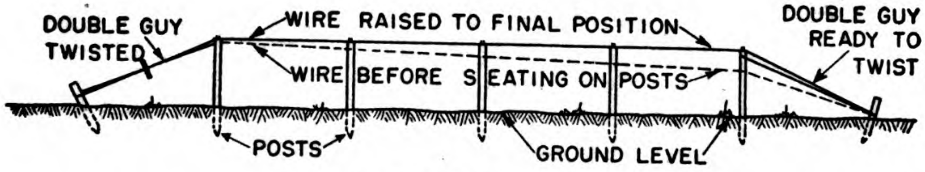
a. Lay posts about 12 feet apart in each direction in the area to be covered.

b. Drive the outside row of posts into the ground so that they will stand alone, and drive strong guy stakes about 12 feet out from them.

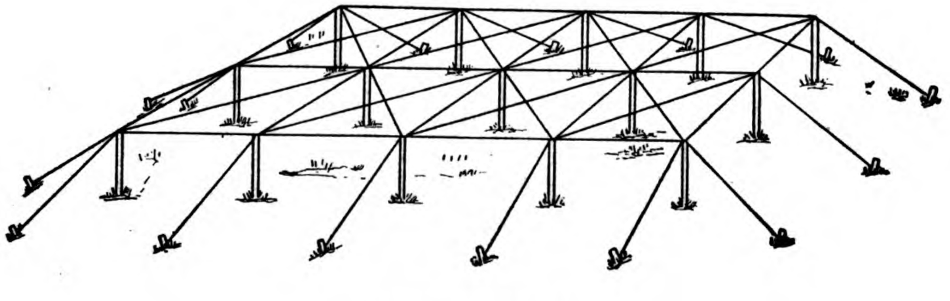
c. Drive two nails about 1 inch apart in the head of each post.


ADDITIONAL POSTS AND WIRING MAY BE ADDED TO THE ABOVE STRUCTURE TO FORM ANY IRREGULAR SHAPE.
ONE METHOD OF COVERING THESE EXTENDED AREAS IS BY TYING GARLANDS TO A LIGHT WIRE FRAMEWORK.
ABOUT 8"
USE FRICTION TAPE OR KINK WIRE TO PREVENT SLIPPING
EXTENDING IRREGULARITIES WITH GARLANDS

PLAN


DOUBLE GUY TWISTED
WIRE RAISED TO FINAL POSITION
DOUBLE GUY READY TO TWIST
WIRE BEFORE SEATING ON POSTS
POSTS
GROUND LEVEL

ELEVATION



PERSPECTIVE

FIGURE 158.—Permanent flat-top.

d. Wind one end of the wire coil around the head of the corner post, 1 foot from top, then take a turn about the guy stake and back over the top of the post between the nails, forming a double guy.

e. Stretch the wire along the line of the posts, using several men. Support the wire by a nail 1 foot below the top of the last post of the row, then give it a turn around the guy stake, bring it back and make it fast 1 foot from the top of the post. Cut the wire from the coil at this point.

f. Push wire up over tops of the posts in the row and seat it between the nails, thus stretching it tight.

g. Proceed thus with each row of posts. Then in the same manner run wires at right angles to the first series, forming squares.

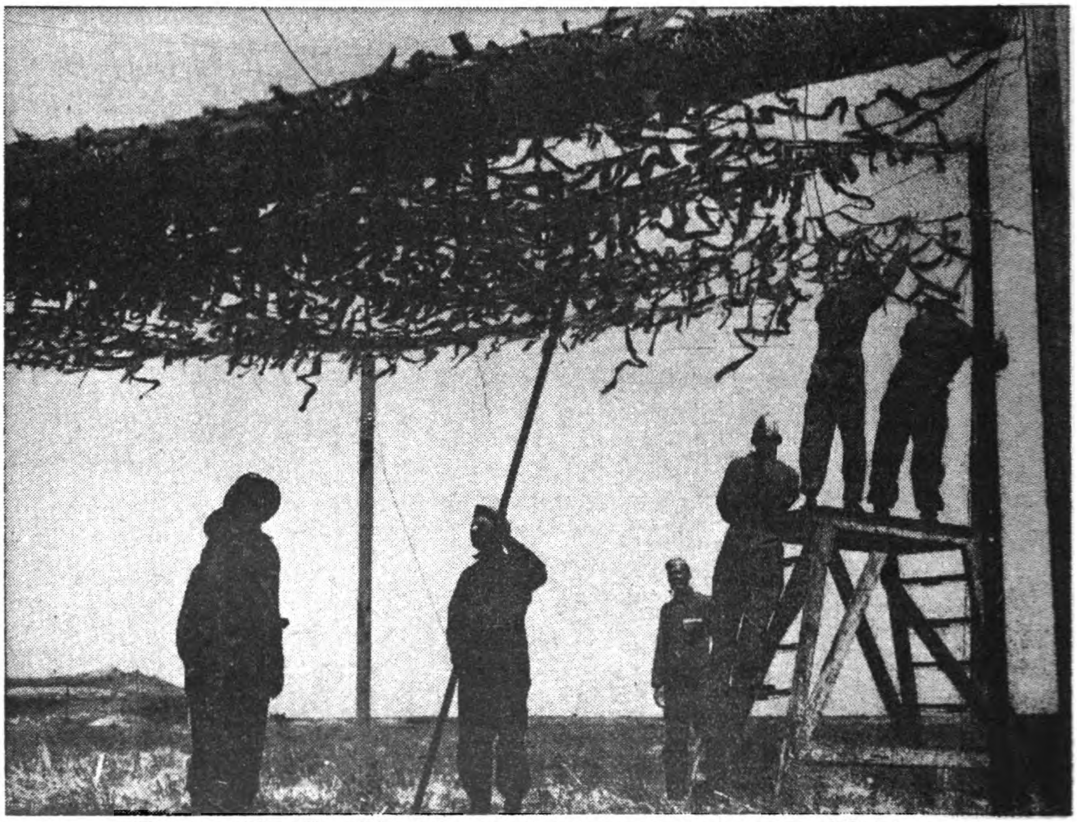


FIGURE 159.—Unrolling wire mesh cover over framework of flat-top.

h. Run the diagonal wire across each line of posts, placing the wires between the nails.

i. Tighten all guy wires by twisting with rack stick or a large nail. Tighten diagonal wires in the same manner at all crossings. This tightens the whole frame.

j. Clinch nails over the wires. Drive them down flat to avoid catching the net when spread.

k. After erection any of the interior posts may be shifted in position to accommodate the needs of the occupying troops without affecting the stiffness of the frame. By placing additional posts on the edge and wiring them as above, any irregular shape may be made.

188. Erection of roll-type flat-top.—*a.* This flat-top, used for antiaircraft guns, is constructed in the same manner as the permanent flat-top already described, with the exception of the roll-top covering the embrasure in the center. Design of the rolling top is shown in figure 160. The 2- by 4-inch runners BC and DE must be kept in line or the roller will bind. The exact height of the flat-top will depend upon the depth of the weapon emplacement.

b. To attach the chicken wire to the frame, place a strip the full length of the top parallel with the runners and with the outside edge a few inches from the wire frame. Attach the ends and the outside edge of the chicken wire to the frame. Lay another strip parallel to the first and about 6 inches from the first. Attach ends to frame, edge to the under side of the runner and then stretch and tie inside edges together. Repeat on other side, then fill in the center and areas F and G.

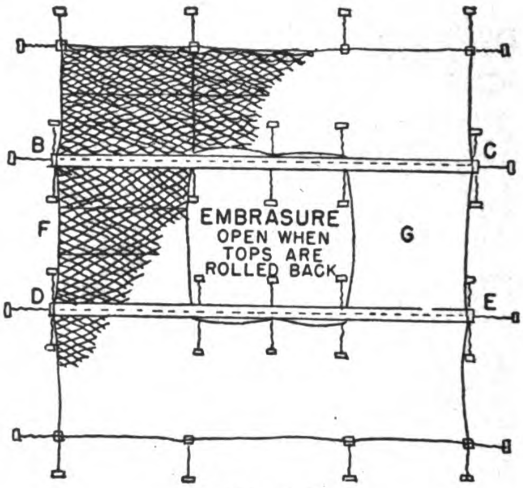
c. Use No. 16 wire to tie and stretch chicken wire together. The runners must always be kept in line; constantly sight along them to keep them straight. This cover can be garnished in the usual manner.

d. The following materials are required for a typical roll flat-top:

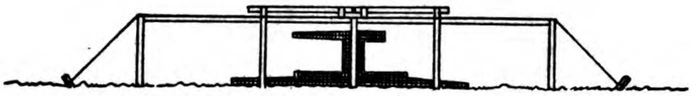
2,300 square feet chicken wire
3,000 linear feet No. 10 wire
300 linear feet No. 16 wire
41 2″ x 4″ stakes
18 2″ x 4″ x 6′6″ posts
4 2″ x 4″ x 14′ runners
4 2″ x 4″ x 10′ runners
8 1″ x 3″ x 12′ runners
8 2″ x 3″ x 10′ runners
4 2″ x 3″ x 11′ runners
36 linear feet 2″ x 7″ braces
8 ¼″ bolts 5″ long
½ pound nails

189. Erection of terraced flat-top.—*a.* The terraced flat-top (fig. 161) is a variation of the usual type. When the height of the top exceeds 6 feet, lower levels are added around the edge to break up its height and to lessen its shadow. Design and construction methods are identical with the preceding flat-tops except that in this case one side has been left open to serve as an entrance for the airplane to be hidden.

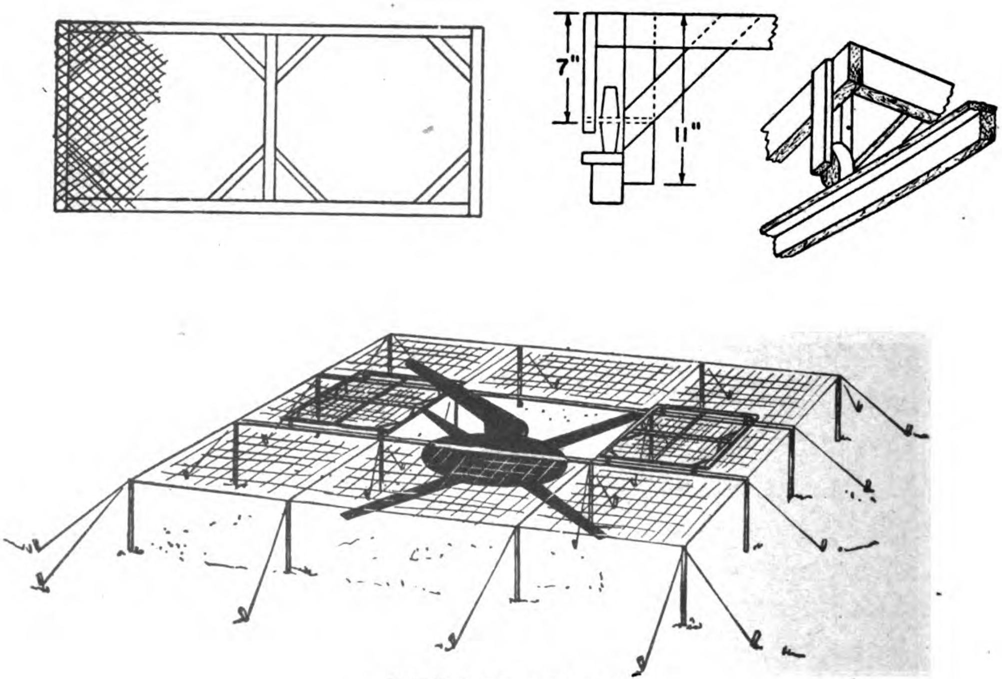
b. For a flat-top 12 feet high, terraces are spaced 4 feet apart in height and extend 6 feet out from the sides of the main top. Where protection from oblique observation is desired each lower level should


B
C
F
EMBRASURE
OPEN WHEN
TOPS ARE
ROLLED BACK
G
D
E

PLAN



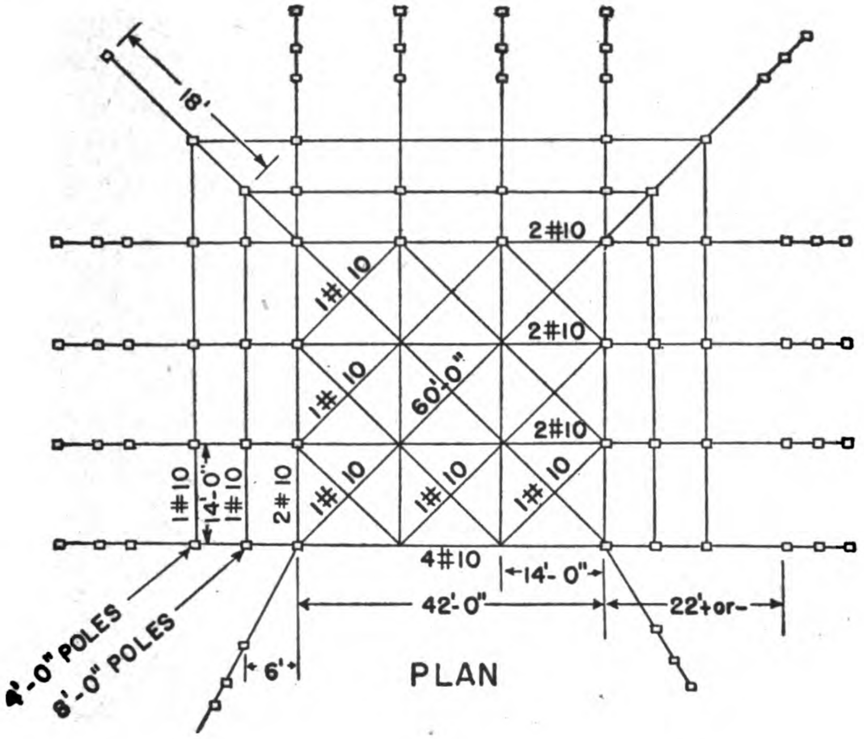
ELEVATION



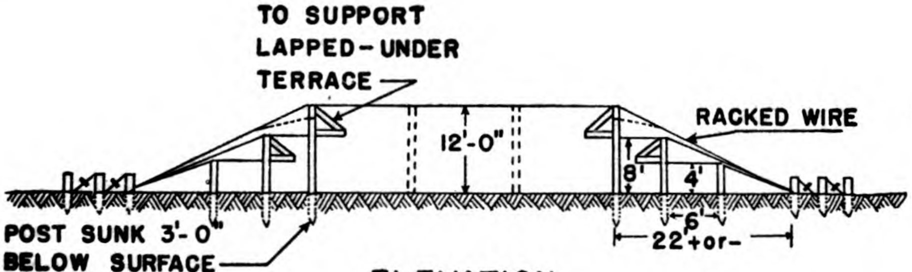
PERSPECTIVE

FIGURE 160.—Roll-type flat-top.

extend under the next higher distance equal to the difference in height. These levels are covered, garnished, and guyed in the same manner as the main top.


18'
2#10
2#10
2#10
1#10
1#10
60'-0"
1#10
1#10
1#10
1#10
14'-0"
1#10
2#10
4#10
14'-0"
42'-0"
22'+or-
4'-0" POLES
8'-0" POLES
6'

PLAN


TO SUPPORT LAPPED-UNDER TERRACE
RACKED WIRE
12'-0"
8'
4'
6'
22'+or-
POST SUNK 3'-0" BELOW SURFACE

ELEVATION

FIGURE 161.—Terraced flat-top.

c. The following materials are required for the terraced flat-top illustrated:

10 corner and side posts 4″ x 4″ x 14′
14 posts 2″ x 4″ x 10′
14 posts 2″ x 4″ x 6′
21 stakes 2″ x 4″ x 5′
28 stakes 2″ x 4″ x 3′

650 feet 2″ mesh chicken wire 6′ wide
3,200 feet No. 10 wire
500 feet No. 16 wire
80 No. 10 nails

190. Erection of fly-top.—*a.* The fly-top (fig. 162) is designed to conceal a pyramidal tent, truck, or press trailer (fig. 142). It is a permanent structure. However, unlike the other permanent structures, it may be easily dismantled and moved. To adapt this cover for vehicles, eliminate the tent, leaving the tent post for the support of the ridge pole.

b. Materials required for the fly-top illustrated are—

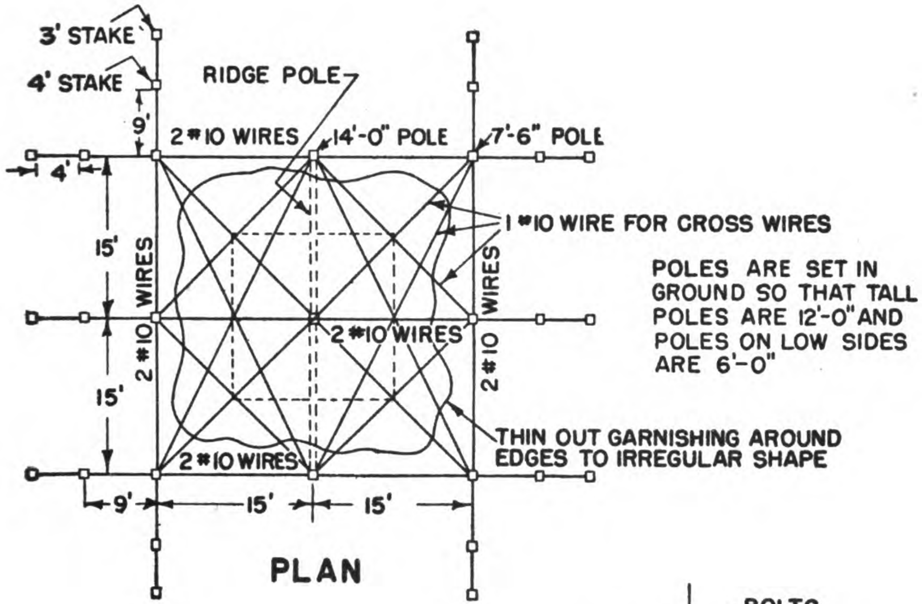
10 stakes 4′ long
10 stakes 3′ long
6 poles 7′ 6″ long
2 poles 14′ long
1 pole 30′ long
1,000 feet or 50 pounds No. 10 wire
5 pieces garnished chicken wire 6′ x 32′
500 feet or 5 pounds No. 16 wire
20 3′ stakes

191. Erection of cantilever flat-top.—The cantilever flat-top (fig. 164) is designed to allow a full 180° field of fire with a machine gun by doing away with one corner post. The 2- by 4-inch diagonal cantilever supports the extended corner of the top. Garnishing is done in the same manner as for the large flat-tops.

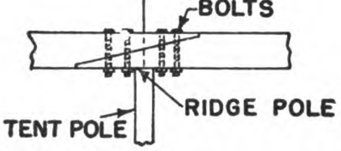
192. Field paint rack (fig. 165).—*a.* This rack provides a layout for wholesale dyeing and cutting of garnishing materials in the field. The paint rack is built entirely of 2 by 4's. It should be located in the shade so that dyed material will dry slowly, allowing the binder in the paint to set. Otherwise, the paint will dust off while handling. The 40-inch material is folded into fourths (fig. 166 ①) to allow it to pass under the stick in the bottom of the G. I. can and up through the wringer (fig. 166 ②). It is then spread out and draped over the 1- by 1-inch sticks to dry, as shown. The dried material is taken from the other end of the rack and cut into 5-foot lengths (fig. 166 ③), rolled tightly and chopped into 2-inch sections with a sharp hatchet (fig. 166 ④). This produces 2-inch by 5-foot garlands.

b. Materials required to construct this plant are—

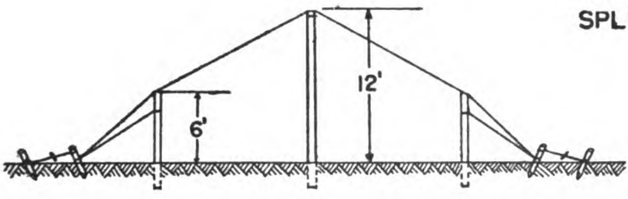
400 feet 2″ x 4″ lumber
200 feet 1″ x 1″ lumber
5 feet wire
1 wringer
1 G. I. can
1 hatchet
1 knife or scissors


3' STAKE
4' STAKE
RIDGE POLE
9'
2 #10 WIRES
14'-0" POLE
7'-6" POLE
4'
1 #10 WIRE FOR CROSS WIRES
15'
2 #10 WIRES
POLES ARE SET IN GROUND SO THAT TALL POLES ARE 12'-0" AND POLES ON LOW SIDES ARE 6'-0"
2 #10 WIRES
15'
2 #10 WIRES
2 #10 WIRES
THIN OUT GARNISHING AROUND EDGES TO IRREGULAR SHAPE
9'
15'
15'

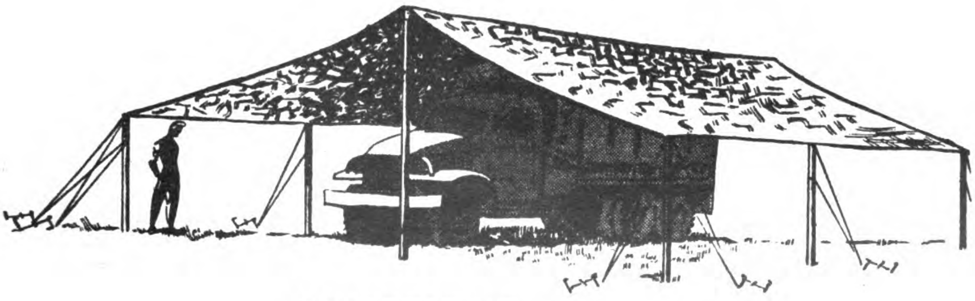
PLAN


BOLTS
RIDGE POLE
TENT POLE

SPLICED RIDGE POLE DETAIL



ELEVATION



PERSPECTIVE

FIGURE 162.—Fly-top.

193. Methods of garnishing (fig. 167).—Garlands produced by the above process are woven into fish nets or chicken wire to form a cover for the various flat-tops. Geometric designs should be avoided. When garnishing is complete the proportion of coverage should diminish from a thick 90 percent at the center, through 50 percent halfway to the edge, to almost nothing at the edge. The garnished area should not run to all edges but should be of an irregular shape. The thickly woven portion conceals what may be under it and the thinned edges cast a faint shadow which merges into the terrain.

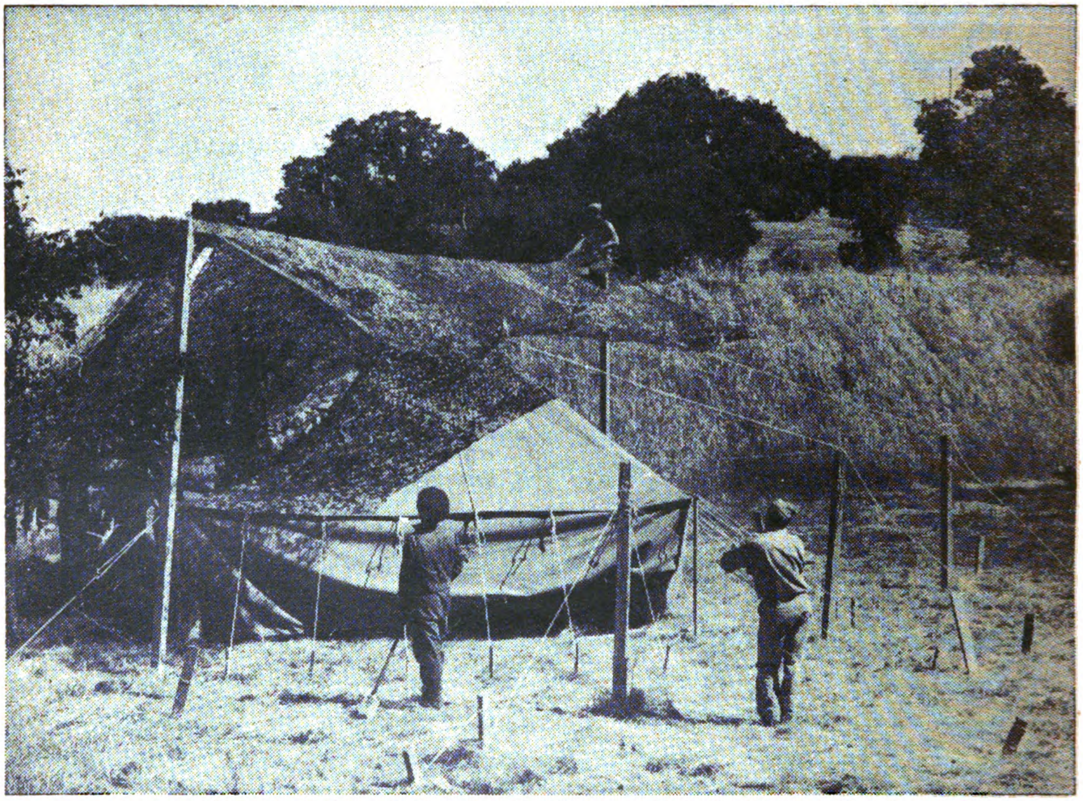


FIGURE 163.—Erection of fly-top. Feather garnished chicken wire is used.

194. Folding nets.—Proper folding of nets produces a compact, easy to handle bundle which unfolds conveniently. One method of folding nets is as follows: First, spread the net flat on the ground and line up men grasping the edge at close intervals on the long sides (fig. 167). The men simultaneously fold the edge in about 18 inches and link their fingers in the net at that point. They repeat this process for succesive folds, hold all previous edges with their fingers, and move forward as necessary, until the two lines meet in the center. The second step consists of lifting one pile of folds up onto the other. This makes a long flat roll of folds. The end men perform the final step by folding the ends into the center, placing one section over onto the other, and tying up the bundle with rope.

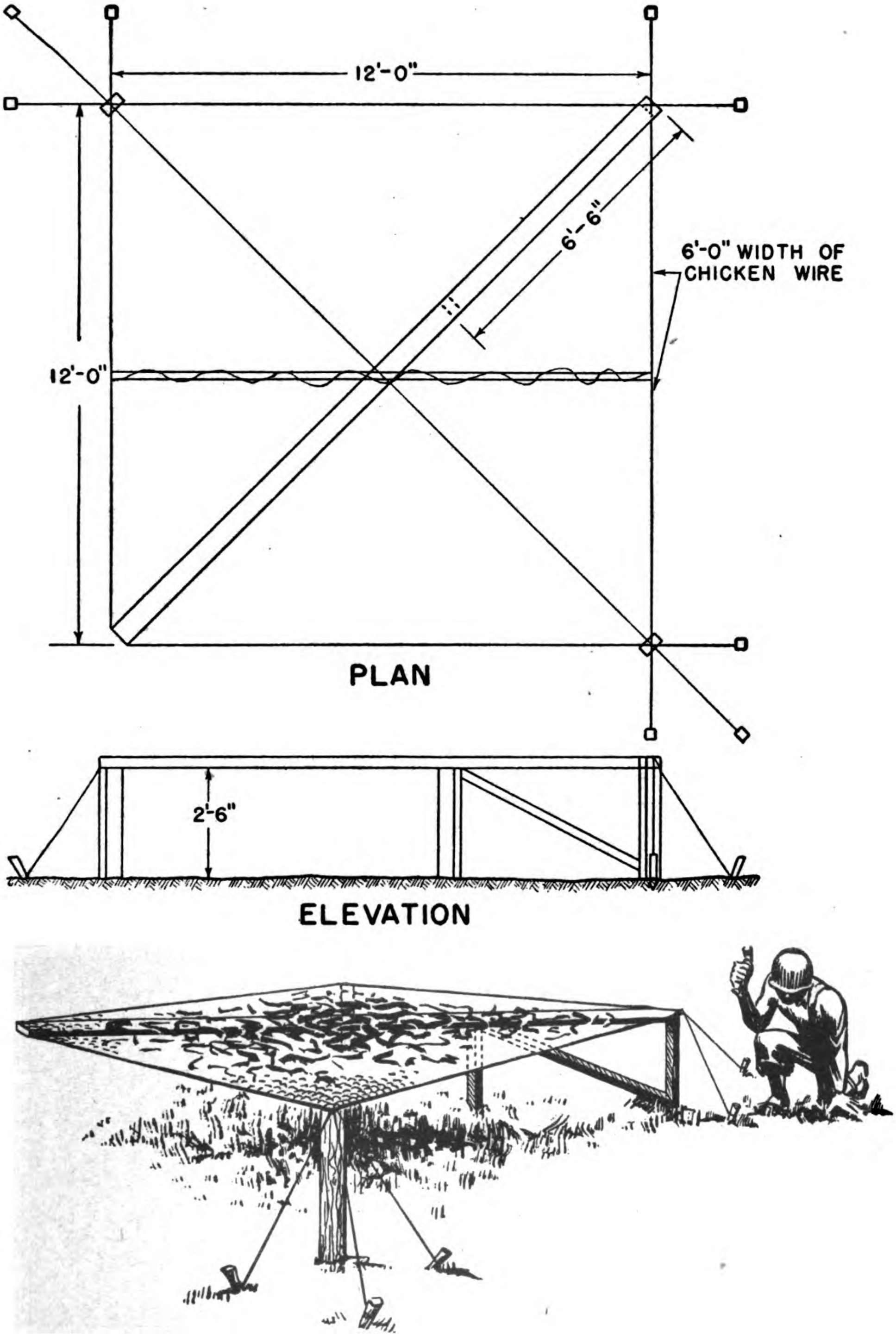

12'-0"
6'-6"
6'-0" WIDTH OF CHICKEN WIRE
12'-0"
PLAN
2'-6"
ELEVATION

FIGURE 164.—Cantilever flat-top.

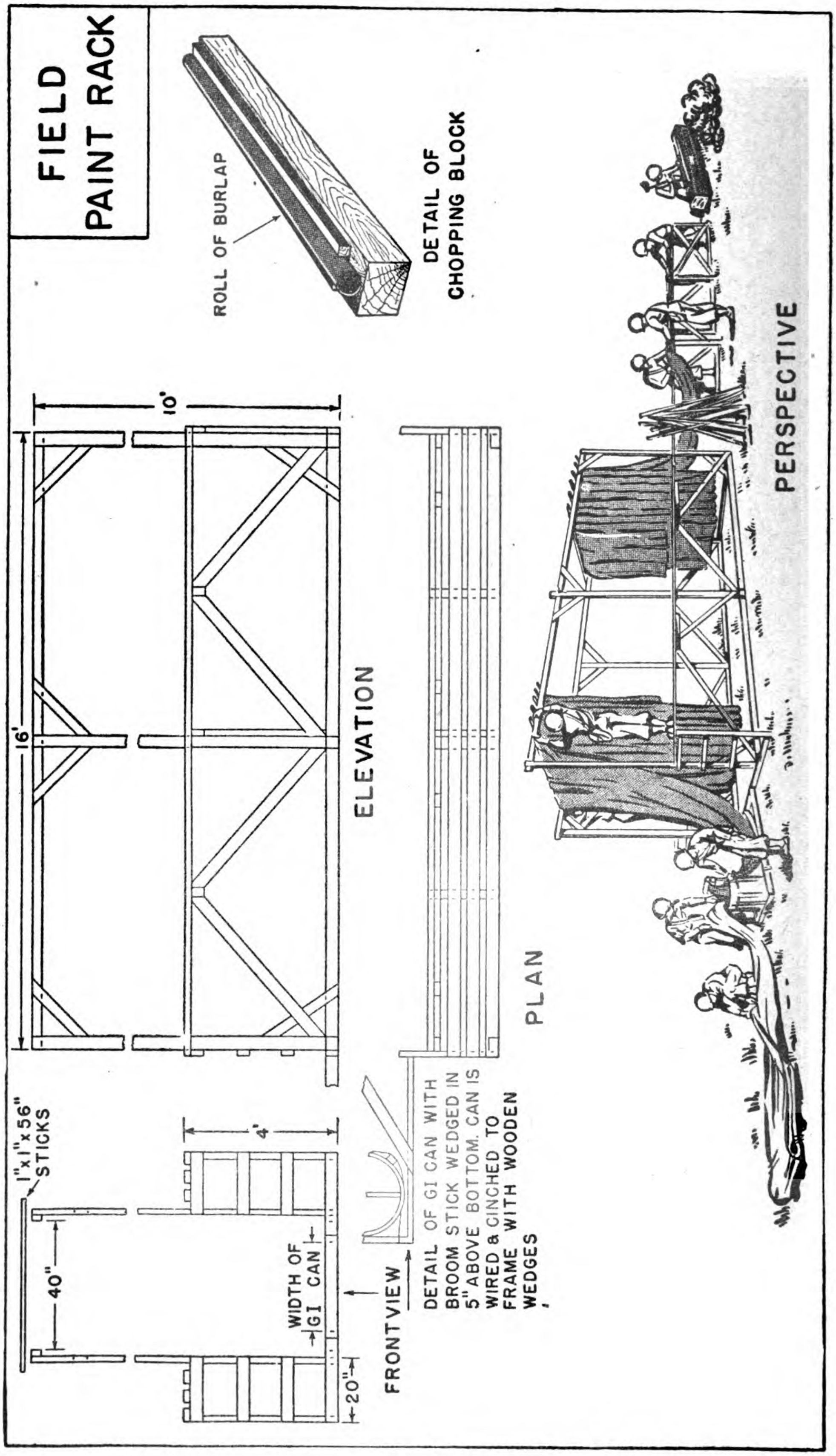
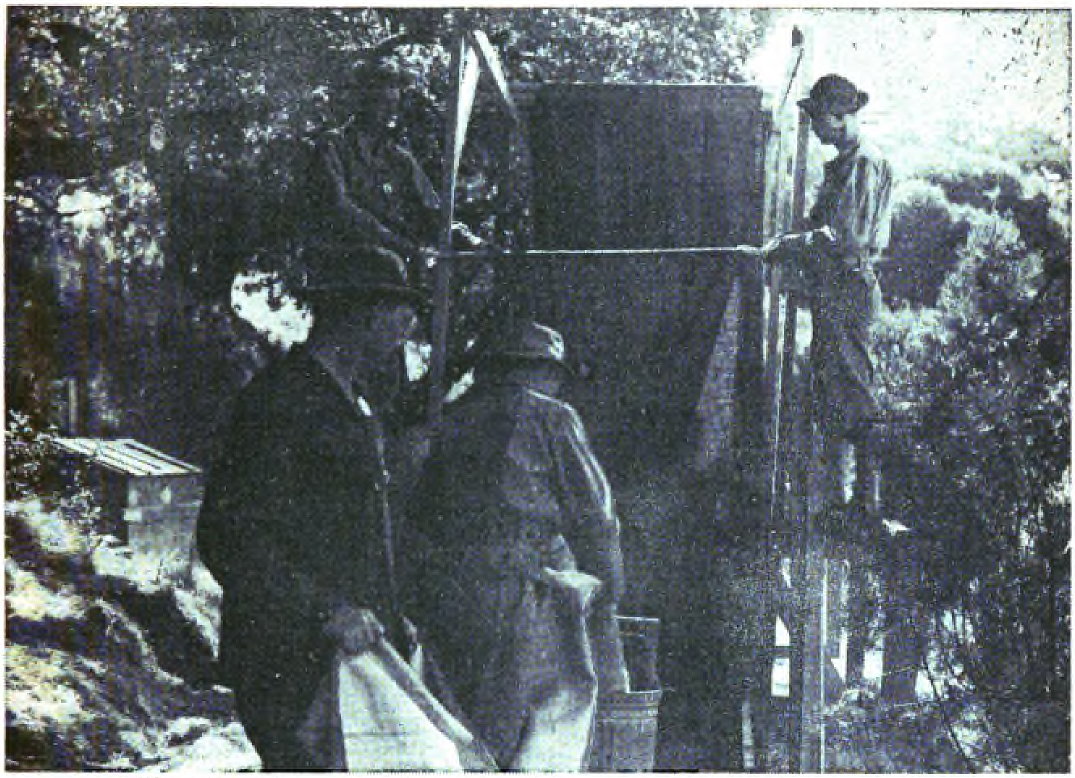
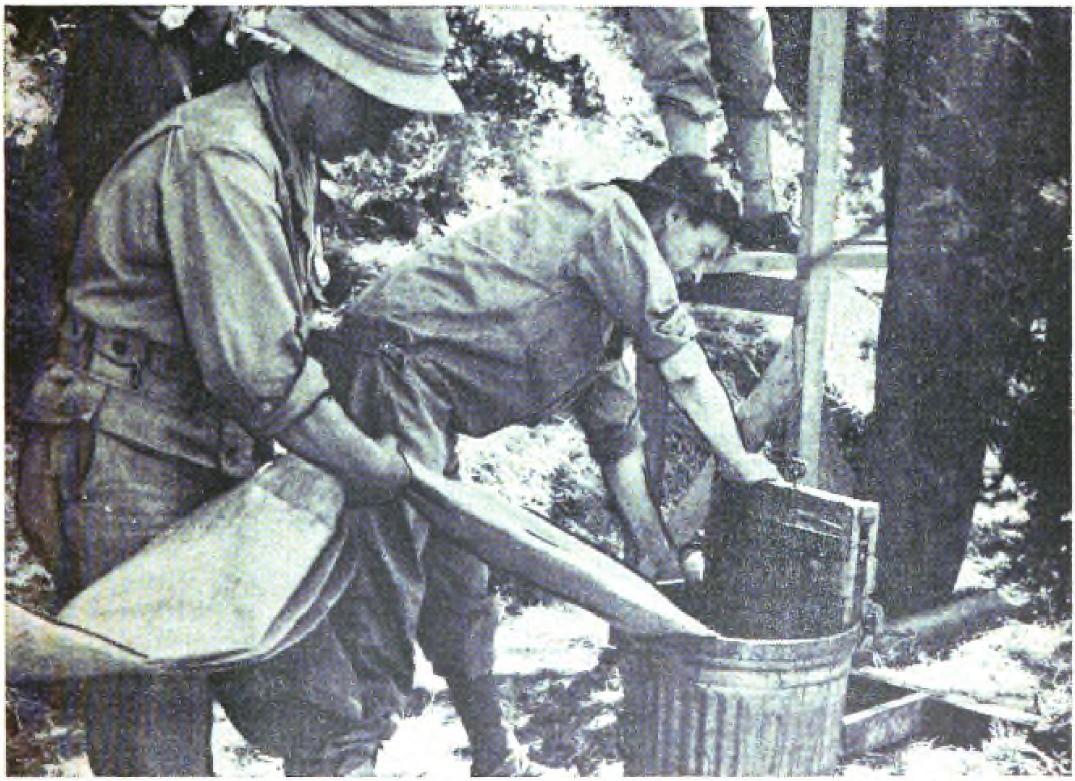

FIELD PAINT RACK
ROLL OF BURLAP
DETAIL OF CHOPPING BLOCK
10'
16'
ELEVATION
PLAN
PERSPECTIVE
1"x1"x56" STICKS
40"
4'
WIDTH OF GI CAN
20"
FRONT VIEW
DETAIL OF GI CAN WITH BROOM STICK WEDGED IN 5" ABOVE BOTTOM. CAN IS WIRED & CINCHED TO FRAME WITH WOODEN WEDGES

FIGURE 165.—Field paint rack.

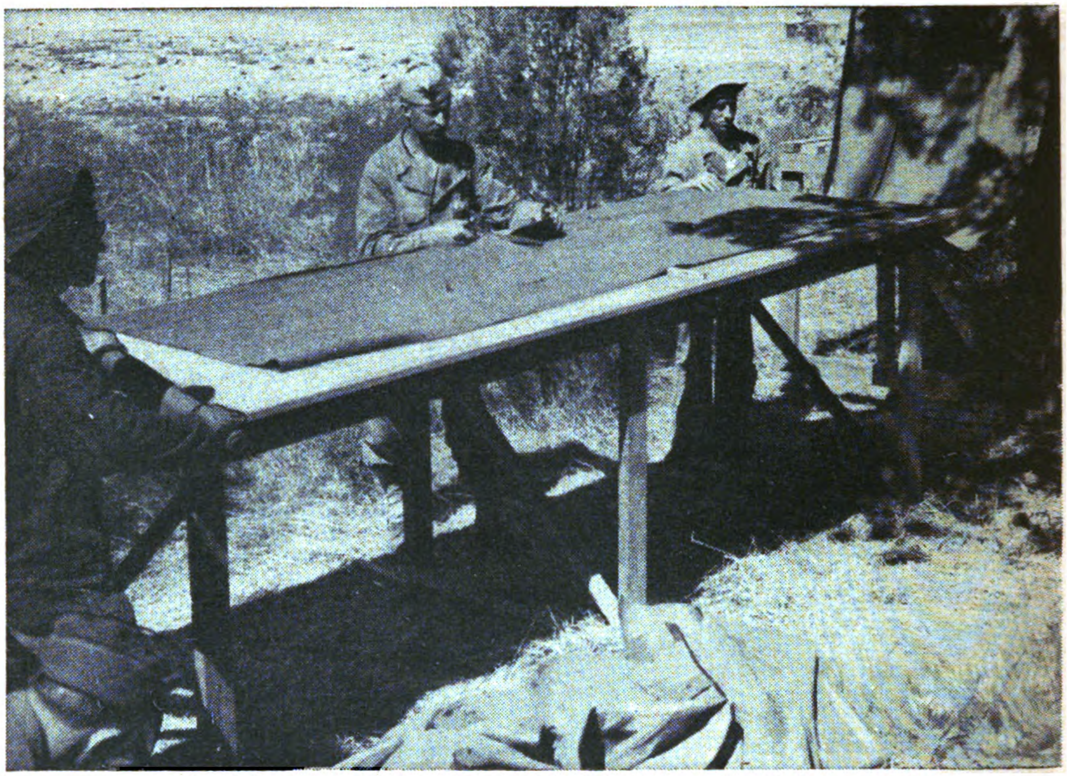


① The wide roll is folded into four thicknesses before entering can of paint.

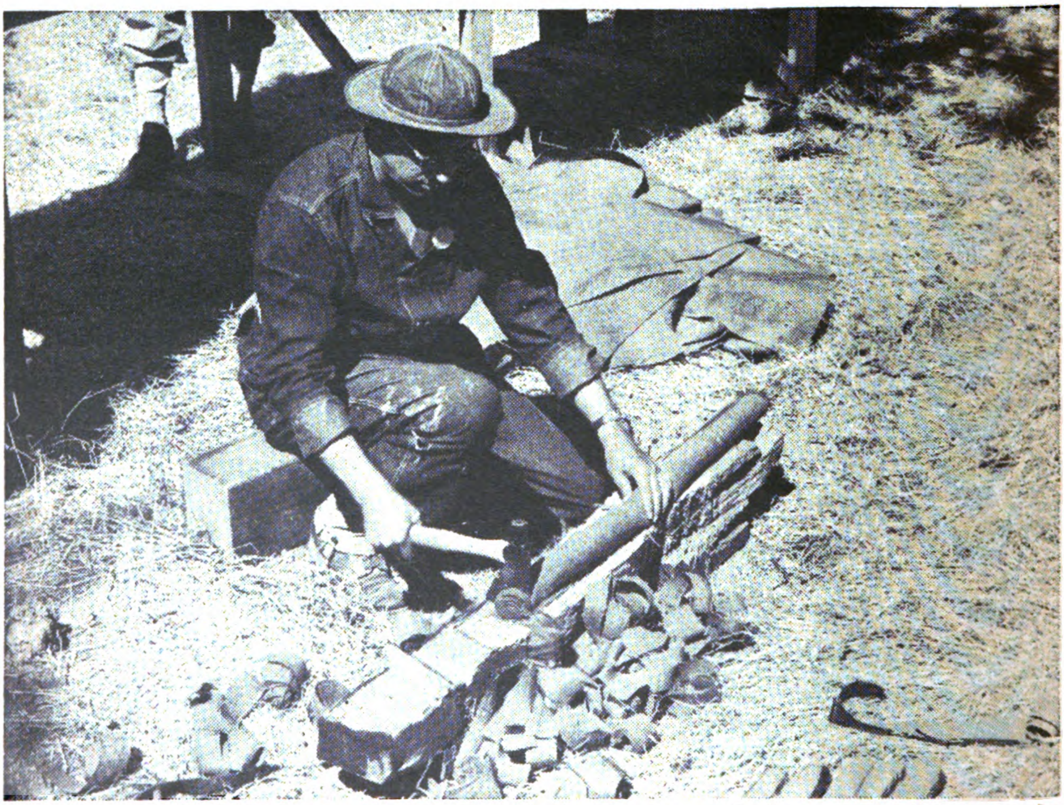


② The cloth passes under a broom handle through paint and up through wringer which squeezes out excess paint. The cloth is then unfolded to its full width and hung in long loops on the drying rack.

FIGURE 166.—Operation of the portable paint rack.



③ The dried material is cut into 5-foot lengths and rolled up snugly.



④ Rolls are cut with a sharp hatchet into 2-inch sections, producing a garland 2 inches by 5 feet.

FIGURE 166.—Operation of the portable paint rack—Continued.

195. Construction of decoy airplane.—*a.* Figure 168 shows a simple and inexpensive design for a decoy airplane. When carefully constructed and properly placed this decoy will serve to draw fire as well as much more elaborate and costly dummies. It has the disadvantage of being fixed in position.

b. All decoy airplanes should represent a definite type, and all airplanes of a given type should be cut from the same pattern if possible, as lack of uniformity in size and shape is very obvious from the air.

c. Cut out osnaburg or other lightweight, strong material according to plans. Sew together with rope in seams and around outer edge. Add loops where they are needed. Sew rope loops securely to fabric to guard against slipping. Make pockets in nose, tail, and wing tips and sew in wood formers. Drill ¼-inch holes near ends of spreaders and sew through holes to secure.

d. To assemble airplane, spread out wing with the fuselage section over it. Drive the stakes and hook on the wing tip ropes. Raise wing with wing tip supports and cinch up the ropes. Next raise and cinch fuselage ropes and attach leading edge of wing to fuselage. Assemble rudder, put in place, and hook front rudder ropes to spreader and cinch up rope over top support and on to stakes.

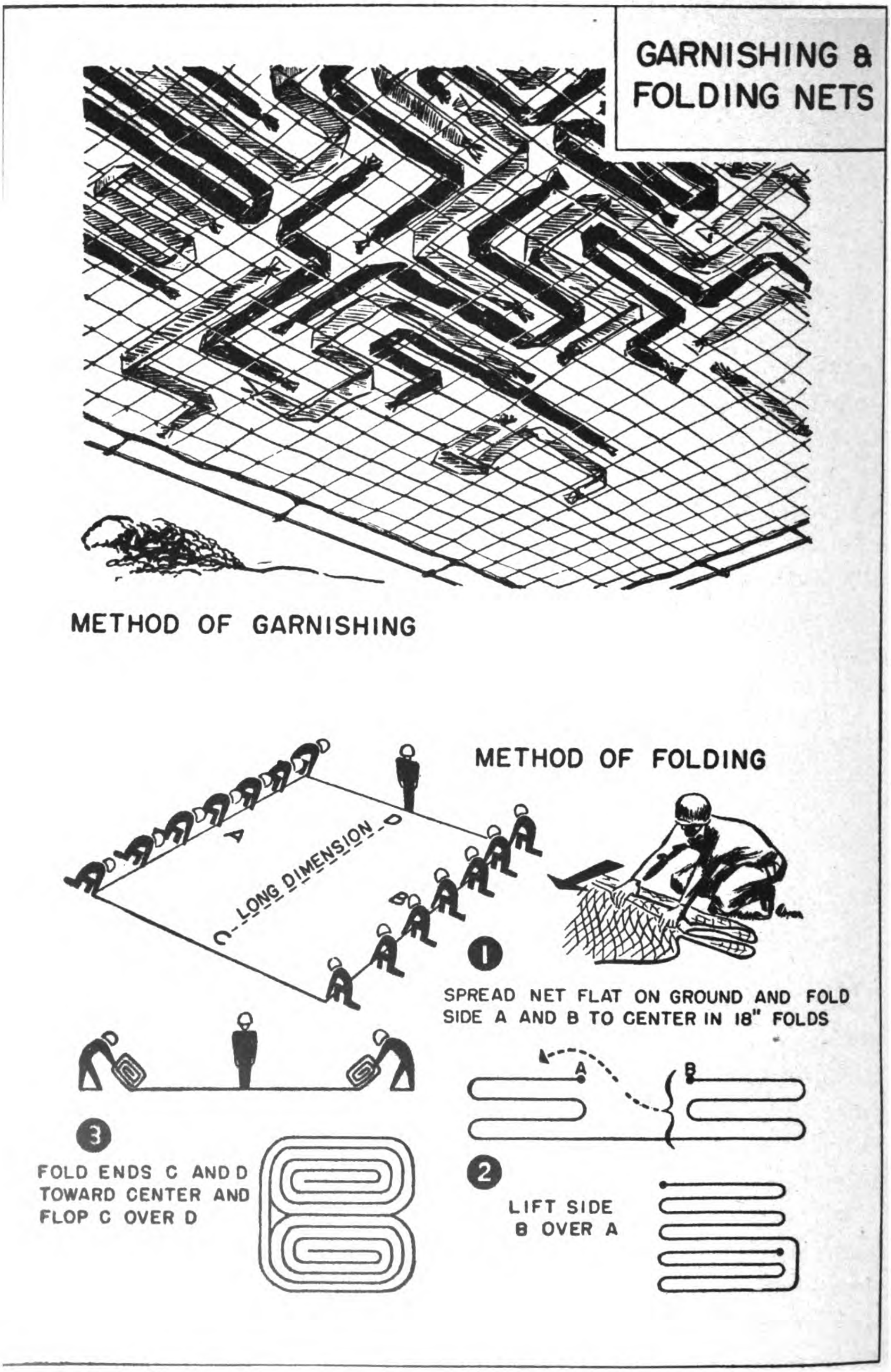
e. Materials necessary for the construction of the decoy are—

200 feet sash cord, wire rope, or No. 10 G. I. wire
100 feet No. 10 G. I. wire
35 square yards osnaburg or burlap
170 feet 2″ x 2″ lumber
40 feet 1″ x 2″ lumber
20 feet 2″ x 4″ lumber
Paint, nails, etc.

196. Decoy guns.—A wide variety of scrap material may be utilized in the construction of decoy guns. The antiaircraft gun (fig. 170) is simple to construct and, while crude in appearance, is convincing from the air. The gun consists of a light frame covered with chicken wire and burlap, then painted. To effectively simulate antiaircraft batteries at night, flash systems can be devised.

197. Construction of portable mat loom.—The portable mat loom (fig. 171) provides a means to fabricate screens from local materials such as rushes, reeds, light brush, or cornstalks.

a. The loom is operated as follows: Fasten three wires (A), stretch to (B), secure around 2″ x 2″; then nail 2″ x 2″ to loom, leaving nail heads exposed for easy removal. Continue wire back to 2″ x 2″ (C), which is alternately raised and lowered as reeds or other material are


GARNISHING & FOLDING NETS
METHOD OF GARNISHING
METHOD OF FOLDING
A
B
C
D
C LONG DIMENSION D
①
②
③
A
B

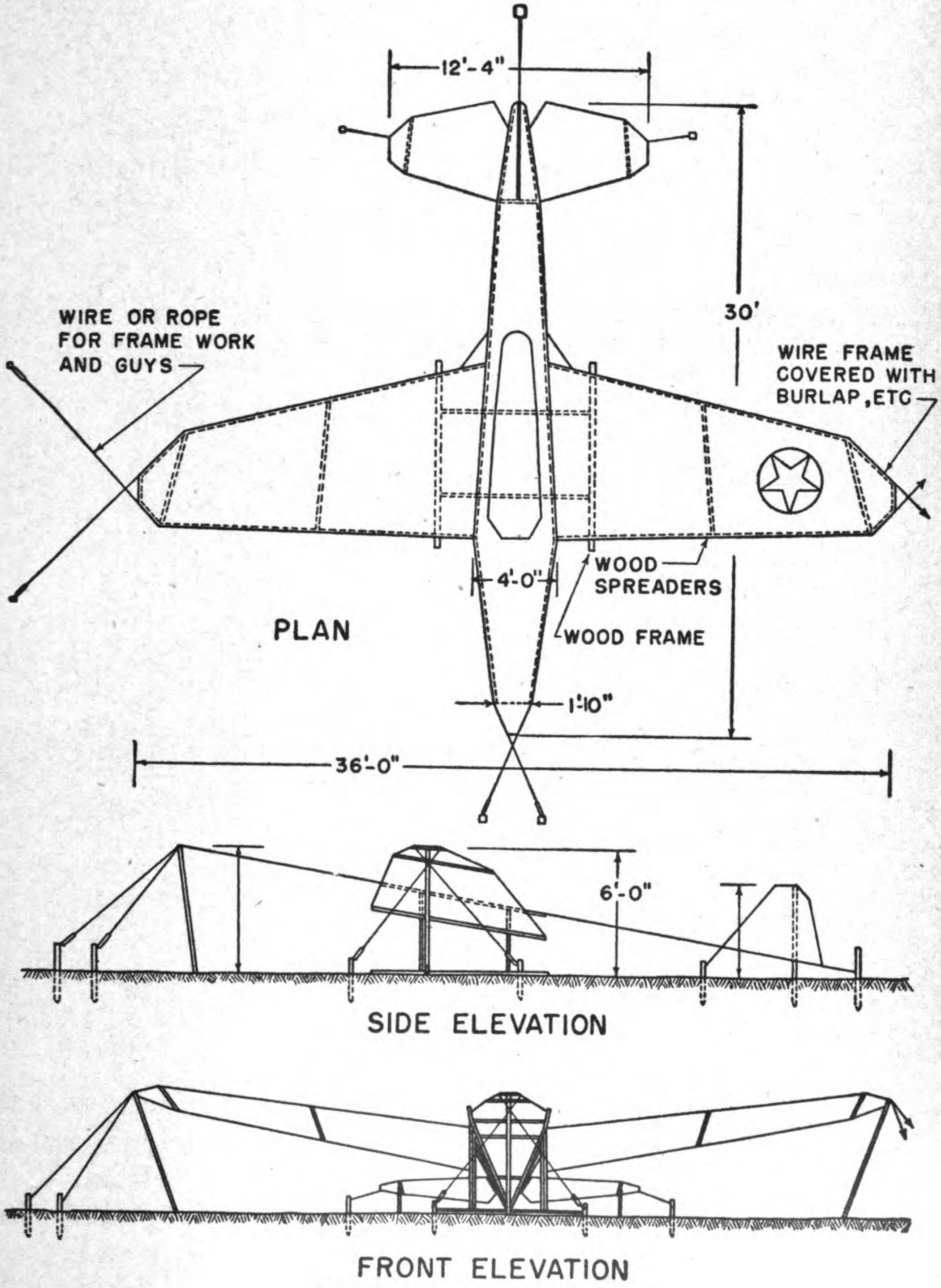
① SPREAD NET FLAT ON GROUND AND FOLD SIDE A AND B TO CENTER IN 18" FOLDS

② LIFT SIDE B OVER A

③ FOLD ENDS C AND D TOWARD CENTER AND FLOP C OVER D

FIGURE 167.—Garnishing and folding camouflage nets.

inserted in about 6-inch sections. Rack wire between the sections as in (D). When woven, cut loose wires from (A) and attach 2″ x 2″ (C) closely to screen. Erect as shown with No. 16 guy wire. If only short lengths of brush are used, more than the three wires may be necessary to hold them in place.


12'-4"
30'
WIRE OR ROPE FOR FRAME WORK AND GUYS
WIRE FRAME COVERED WITH BURLAP, ETC
WOOD SPREADERS
4'-0"
WOOD FRAME
1'-10"
36'-0"
6'-0"

PLAN

SIDE ELEVATION

FRONT ELEVATION

FIGURE 168.—Decoy airplane.

b. The necessary materials are—

18 feet 1″ x 4″
120 feet 2″ x 4″
8 feet 2″ x 6″
175 feet No. 16 wire
16 feet 2″ x 2″
4 stakes 2″ x 2″

198. Artificial rocks and trees (fig. 172).—Artificial rocks and trees have a definite place in concealment. Several methods of construction are shown here and all of them can be made quickly.

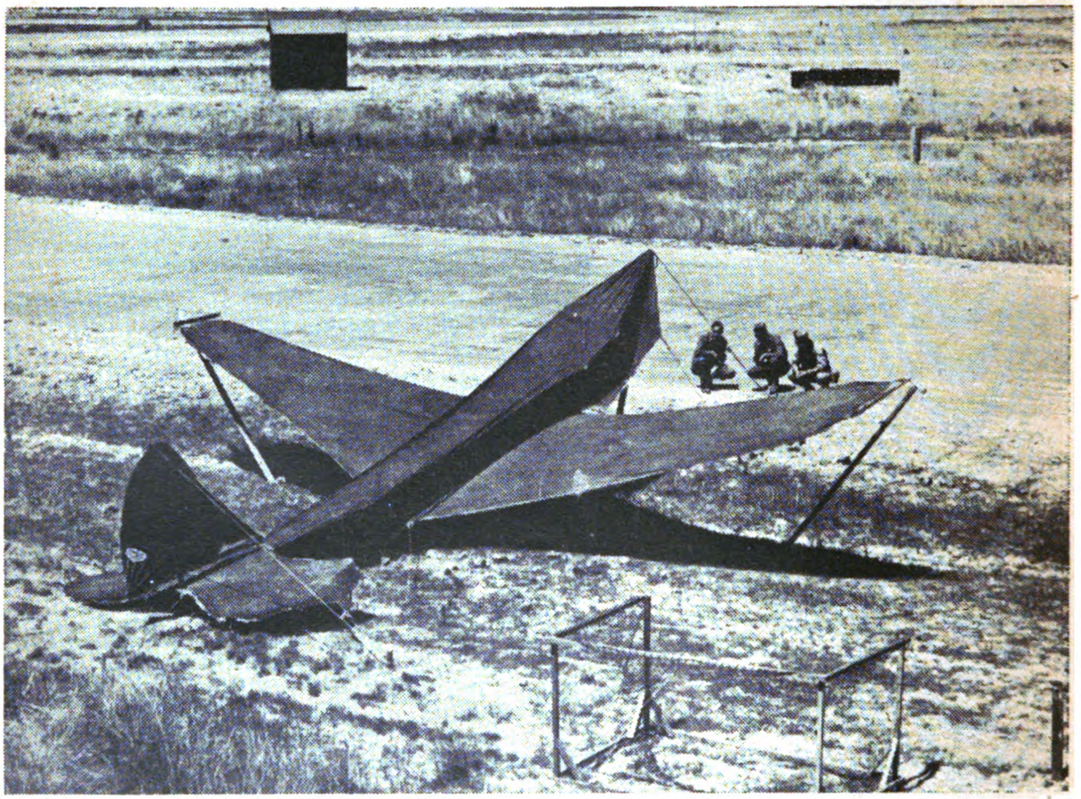


FIGURE 169.—Decoy airplane constructed of fabric. An apparent attempt to conceal this decoy will make it more realistic.

a. Artificial rocks may be used as covers for foxholes, machine gun nest (fig. 173① and ②), and command posts, and are important on runways and flat-tops to break up the smooth, regular surfaces.

b. Type A is made on a 2- by 4-inch wood base with No. 10 wire twisted to form a rough outline of the rock. Chicken wire is then fastened to the wire frame and covered by the papier-mâché method. With paste and brush stick on overlapping 4-inch to 6-inch squares of newspaper until about 10 layers have been built up. Allow to dry, then paint simulating the surrounding rocks.

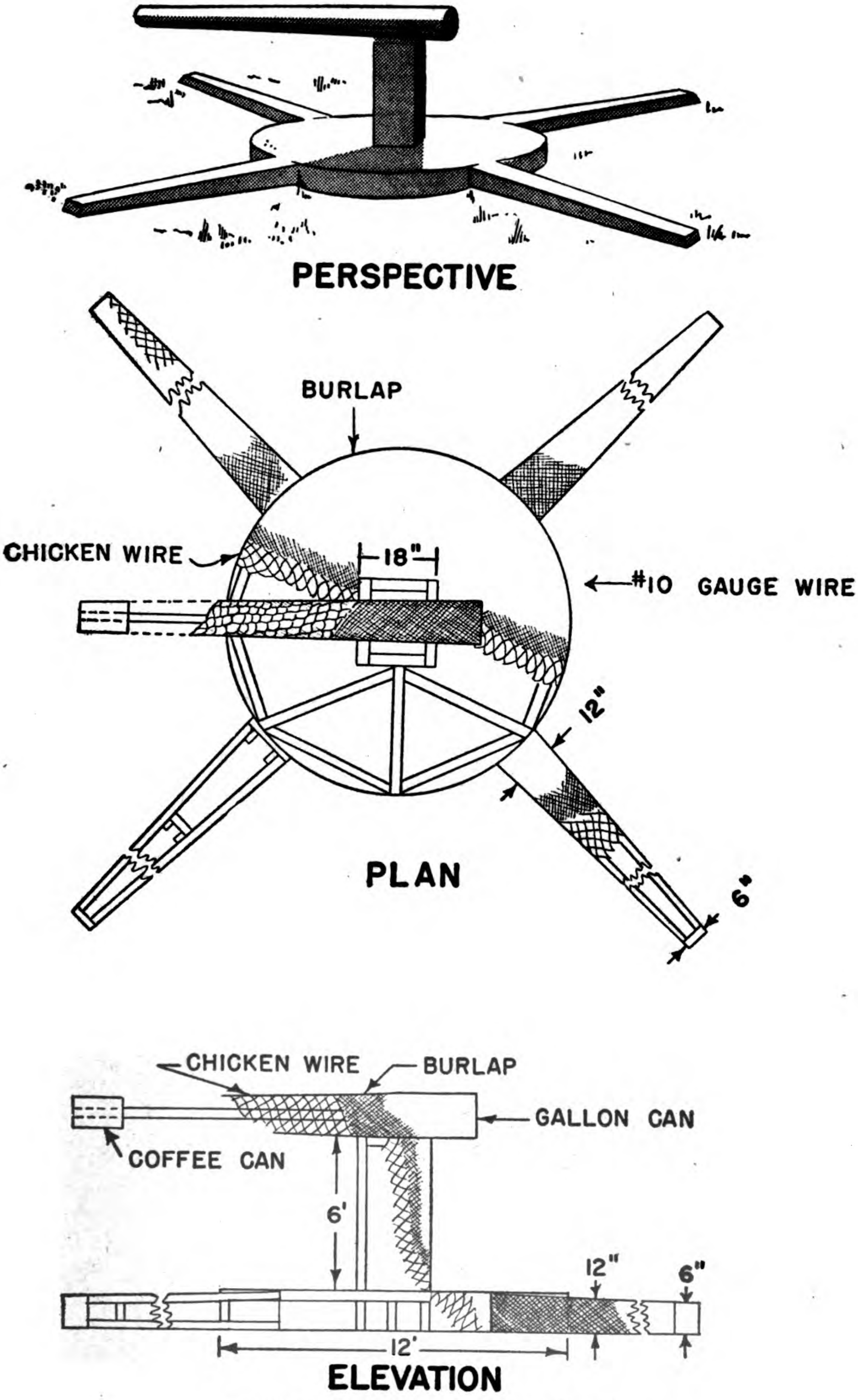

PERSPECTIVE
BURLAP
CHICKEN WIRE
18"
#10 GAUGE WIRE
12"
6"
PLAN
CHICKEN WIRE
BURLAP
GALLON CAN
COFFEE CAN
6'
12"
6"
12'
ELEVATION

FIGURE 170.—Decoy antiaircraft gun.

c. Type B is built without the wood frame and with burlap replacing paper. After the burlap has been wired in place, paint with a cover coat of the dominating color of the surrounding rocks and "spatter paint" with a variety of color to blend in with them.

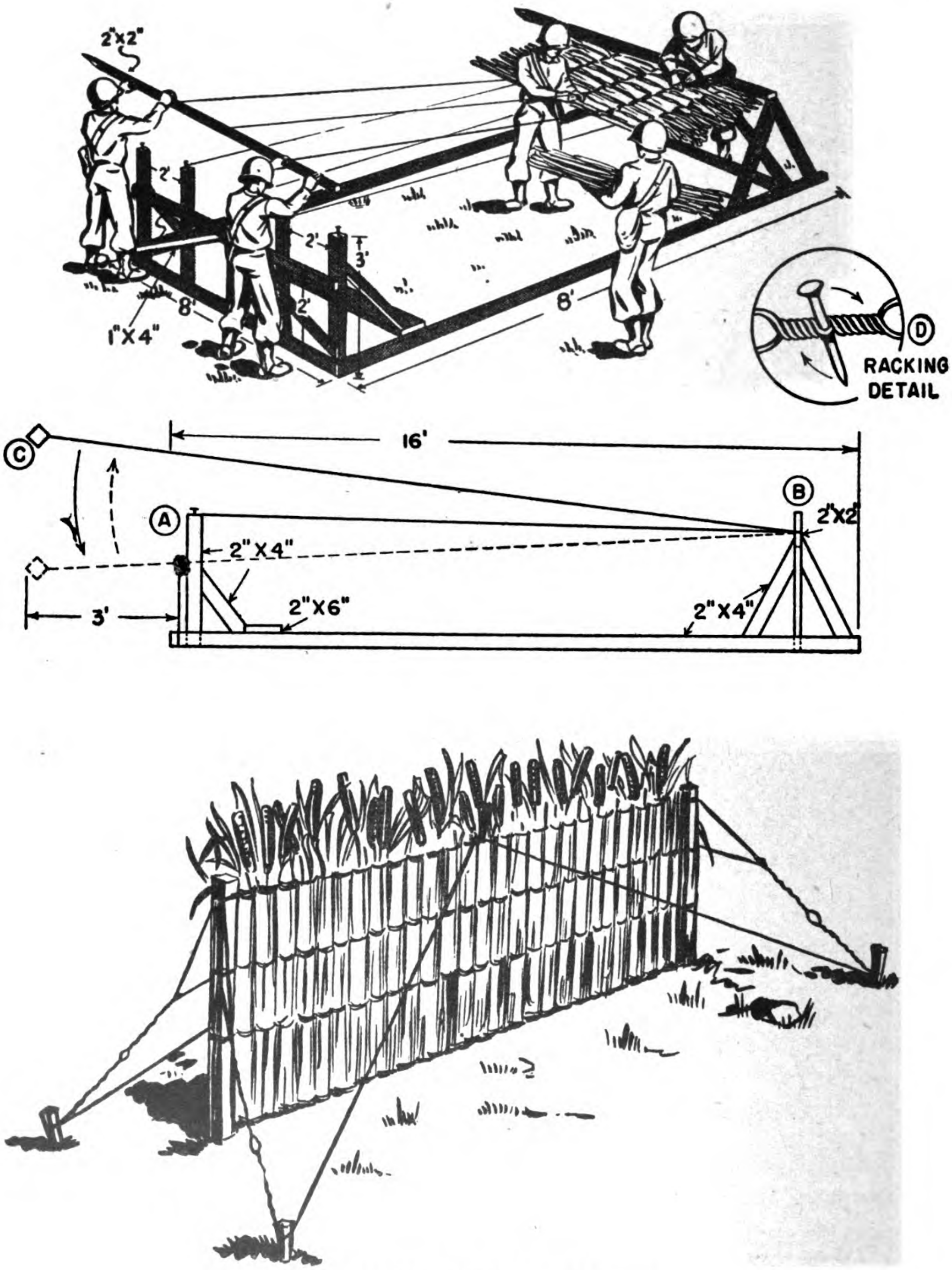

2"x2"
2'
2'
3'
2'
8'
8'
1"X4"
D
RACKING DETAIL
C
16'
A
B
2"X2"
2"X4"
2"X6"
2"X4"
3'

FIGURE 171.—Portable mat loom.

d. Type D is an artificial tree consisting of a central pole supported by guy wires and three planes of garnished chicken wire. It is simple to construct, requires little material and casts a very realistic shadow.

e. Type E is a treatment of natural shrubbery which has been attached to an artificial trunk. The shrubbery is painted with a preservative color matching existing trees, to compensate for fading leaves.

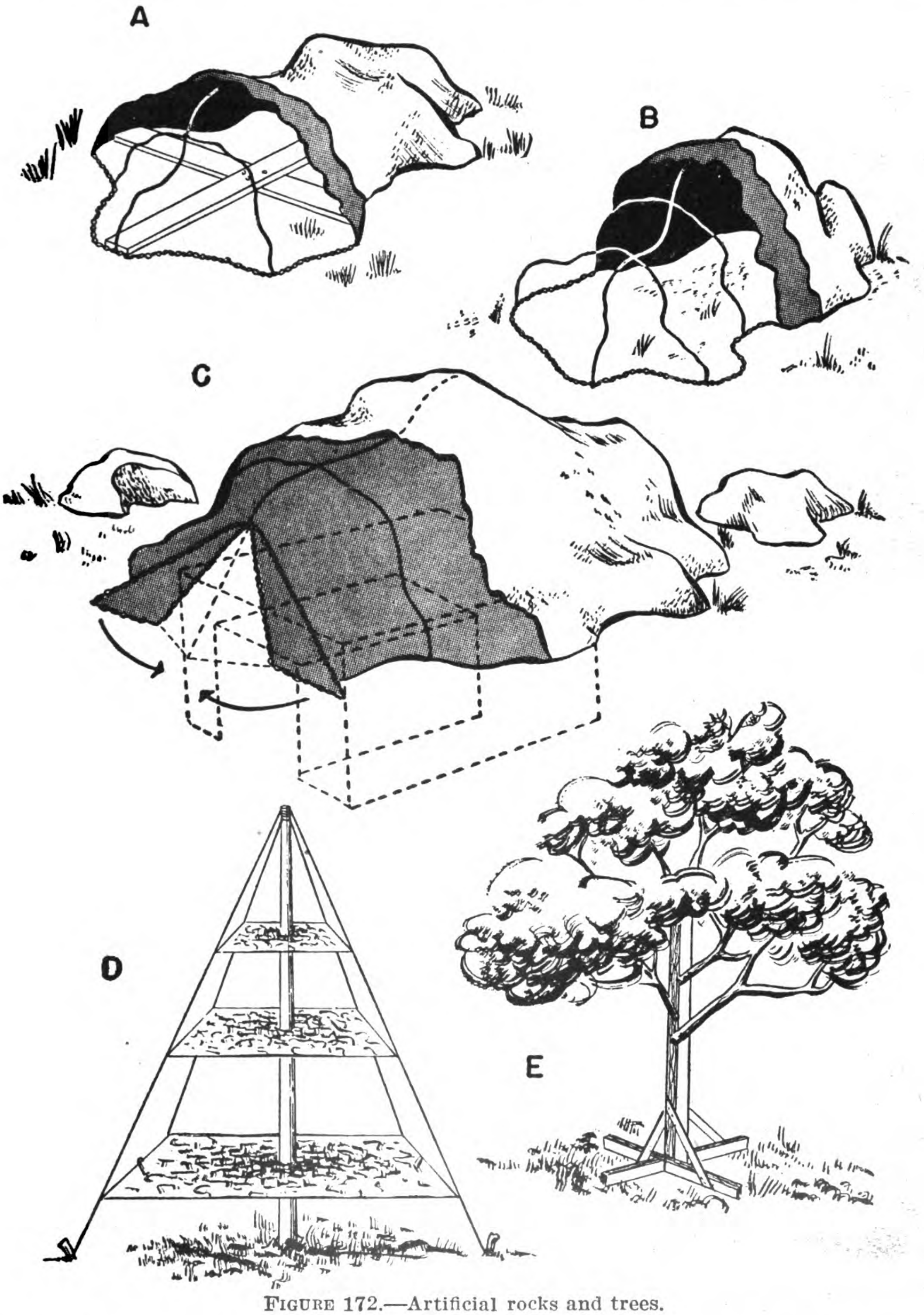
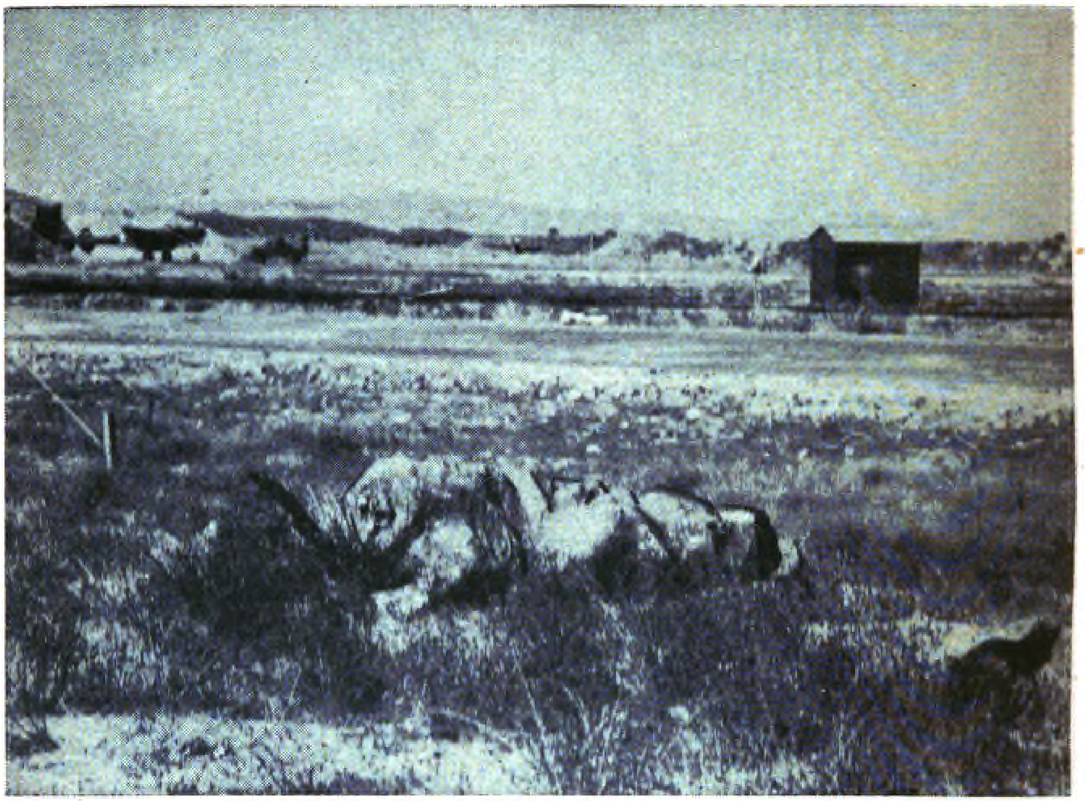
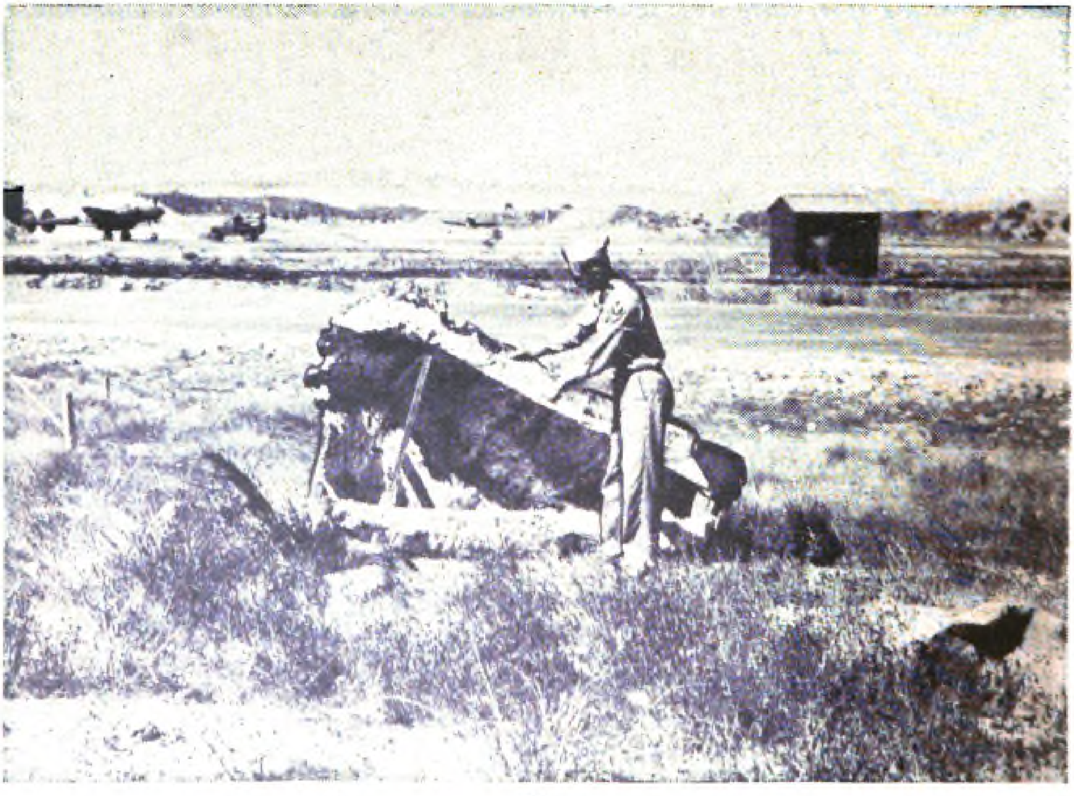


FIGURE 172.—Artificial rocks and trees.



①



②

FIGURE 173.—Artificial rocks. May be used to conceal snipers and **machine-gun positions**: also to break up flat expanse of runway.

SECTION VI

CONCEALMENT OF AIRCRAFT ON THE GROUND

Paragraph
General 199
Use of terrain features and natural cover 200
Drapes and flat-tops 201

199. General.—*a.* The concealment of aircraft on the ground is not the task of a few specialists. In many cases camouflage troops may build elaborate flat-tops, artificial covers, and decoys; but in general the operating personnel and ground crews must accept the responsibility of parking airplanes in dispersed areas and of concealing them by using natural cover and artificial drapes and covers. *Airplanes which are not concealed will not stay in action.*

b. Dispersion of aircraft is the first consideration in protective concealment. This principle is universally recognized; but despite this it is frequently violated in practice since operating difficulties increase as airplanes are dispersed. The necessity for dispersion must control in order to prevent surprise attacks from causing serious loss of airplanes by bombing and strafing.

c. In concealing dispersed airplanes it is necessary to break up both the form and the shadow of the airplane. Terrain features and natural cover are utilized; nets used as drapes or flat-tops reduce the telltale shadow and form; and decoy airplanes mislead and confuse the enemy observer. This section briefly summarizes the steps in connection with concealment of aircraft. Decoys are not discussed because they are covered comprehensively in TM 5-266.

200. Use of terrain features and natural cover.—*a.* Even the most barren plain has certain terrain features which assist camouflage. If airplanes are parked close to small hills and knolls, their visibility may be reduced by the irregularities in the ground. Shadows are less conspicuous if they fall on uneven and irregular surfaces such as rock outcroppings, brush, or folds in the ground (fig. 174).

b. Wooded areas generally afford the best concealment. Airplanes are backed into the edges of woods or into clumps of trees with only as much cutting of the cover as is absolutely necessary for tail, fuselage, and wing clearances. Even very scant cover or minor terrain irregularities assist concealment, particularly if supplemented by other means (figs. 148, 175, and 176). Never use artificial means of camouflage until maximum advantage has been taken of the natural features of the ground.

201. Drapes and flat-tops.—Although drapes and flat-tops may be used in the open (figs. 151 and 178), they should be used in conjunction with natural cover where possible.

a. Drapes are garnished nets drawn directly over planes with a light framework, or no framework at all, for support (fig. 178). In order to break up the form of the airplane, the net should be drawn tightly away from the plane to allow it to touch in as few places as possible. Standard drapes have been designed for each type of airplane, and will be available at all airdromes.

b. Flat-tops (par. 187) for aircraft must be very large if they are to be used in open terrain. Such flat-tops are laborious to construct and maintain. More frequently they are used to fill in gaps in natural cover. Flat-tops should be constructed as close to the ground as possible; generally, terraced flat-tops (par. 189) are built for heights over 6 feet. The entrances may have garnished nets drawn across them or they may have screens made from natural materials (par. 197). It should be emphasized that proper selection of cover reduces the size of the flat-top required.

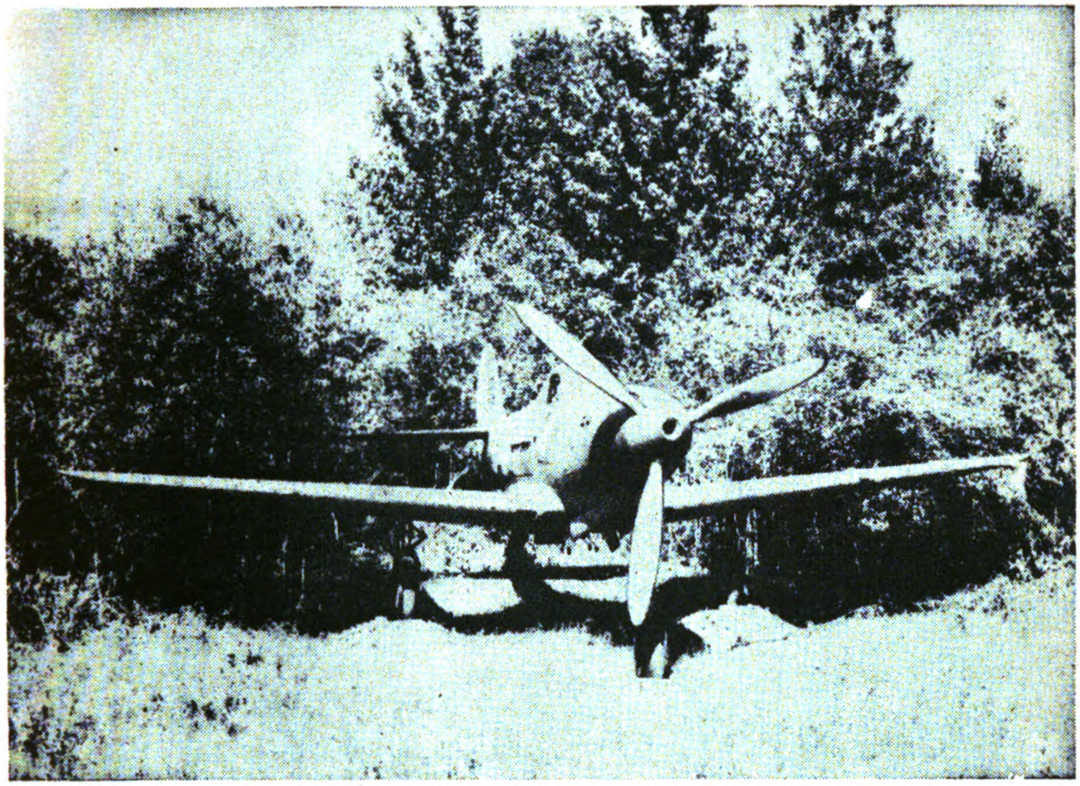


FIGURE 174.—Shrubbery surrounding airplane breaks up shadow.

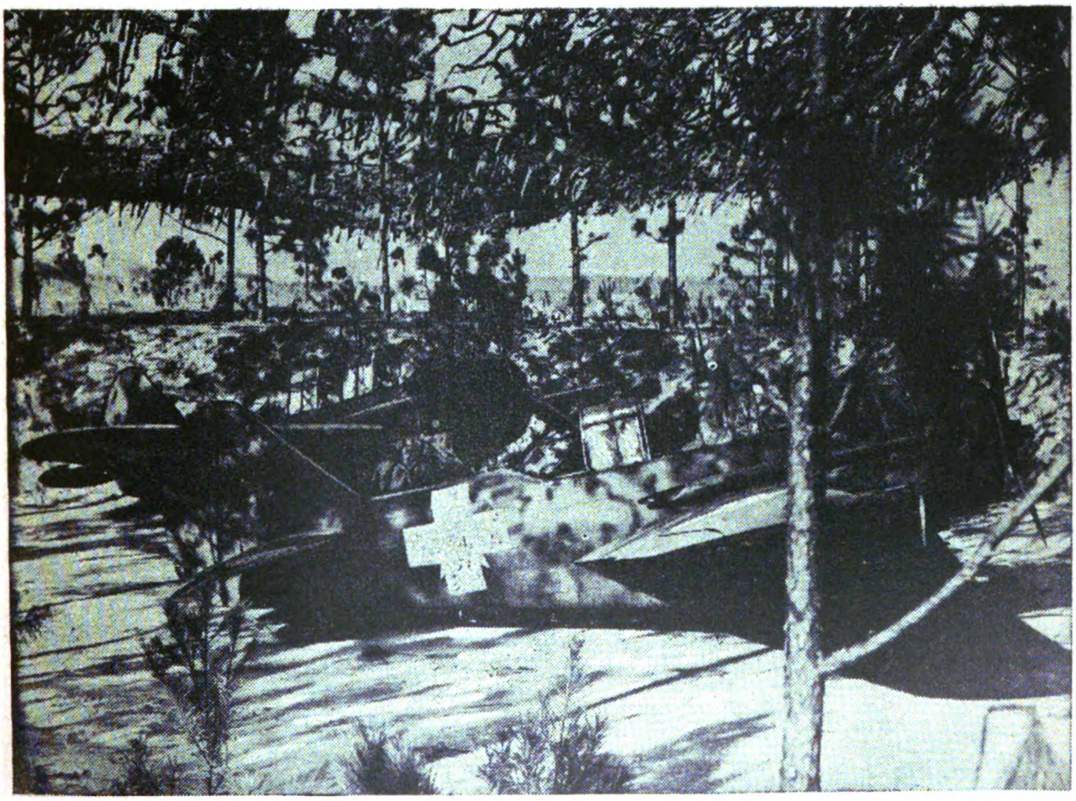


FIGURE 175.—Flat-top over airplane in revetment ties in with small trees. Garlands should be woven horizontally to save material.

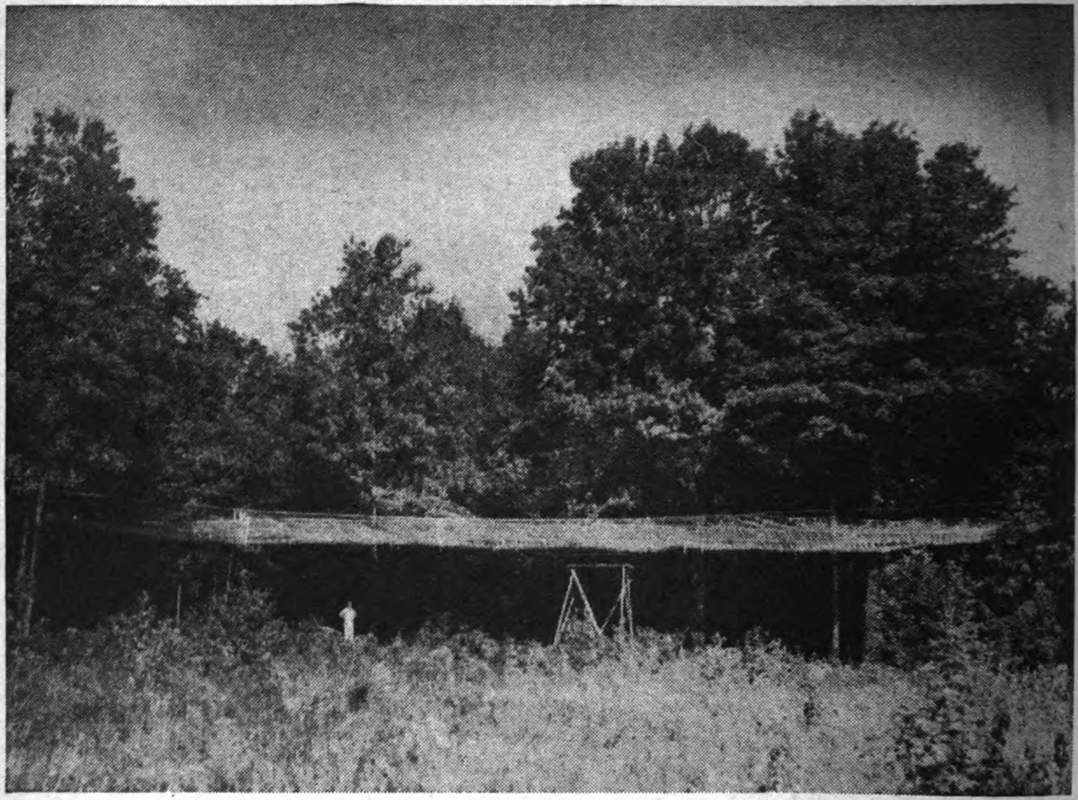


FIGURE 176.—Large flat-top supplements natural cover.

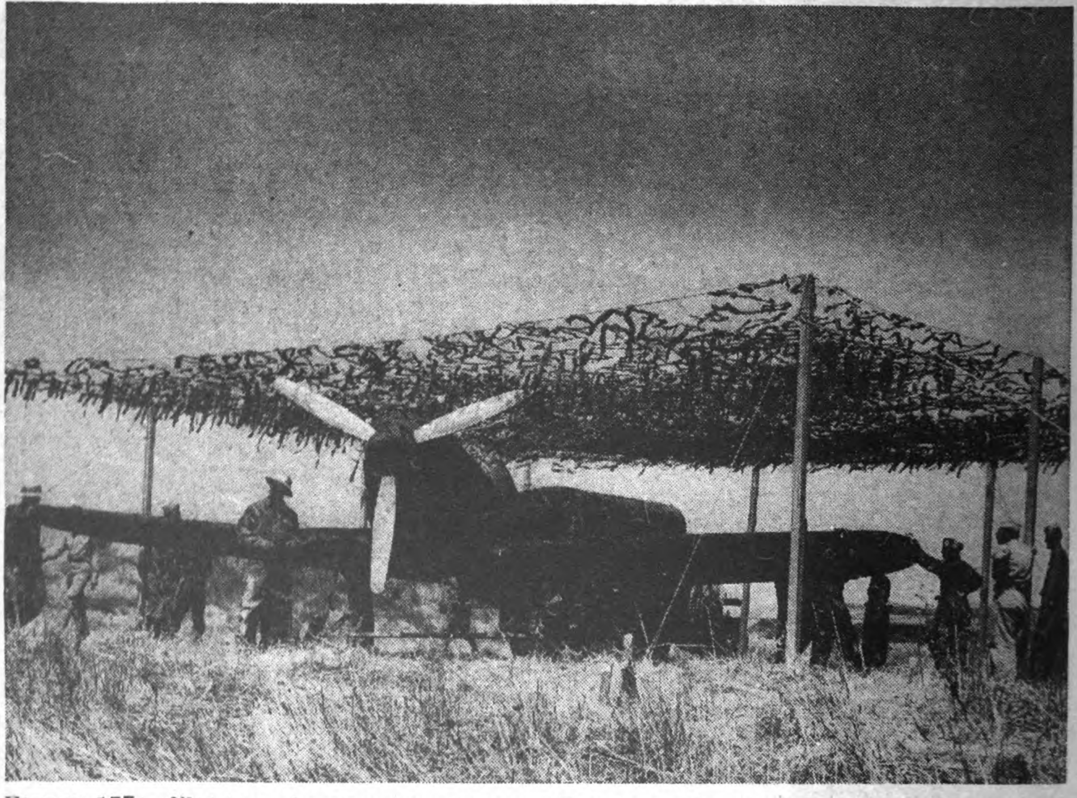
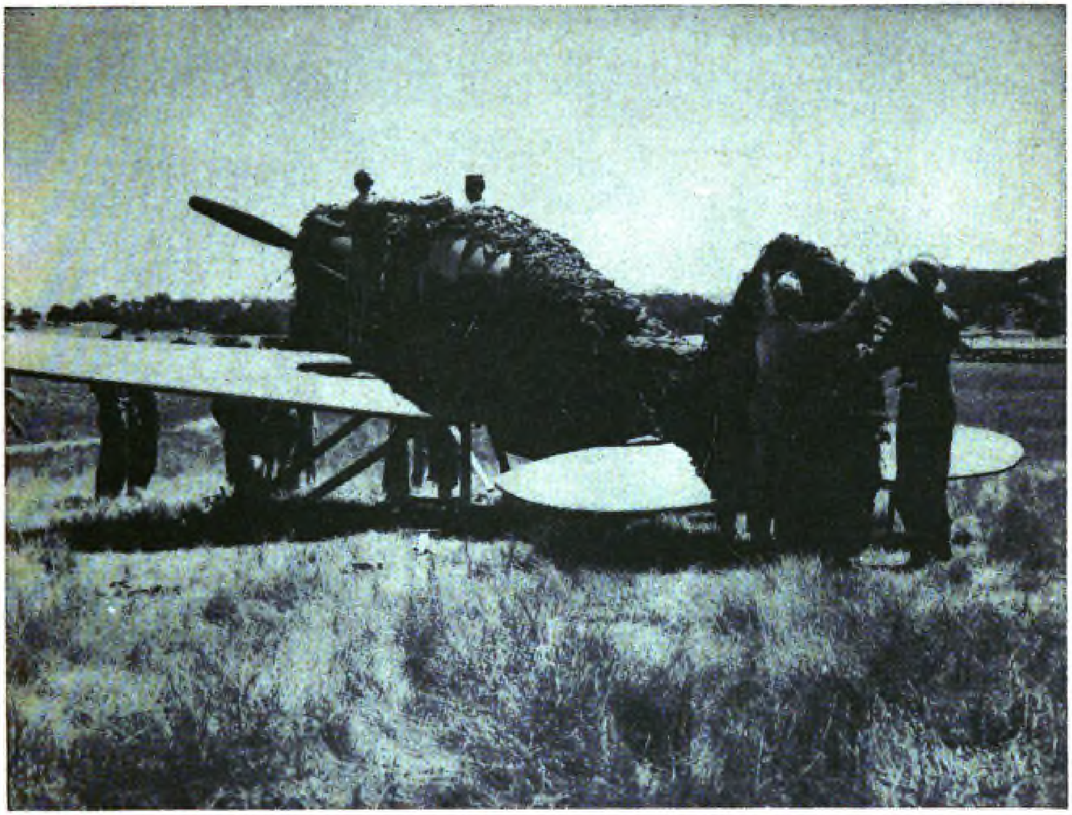
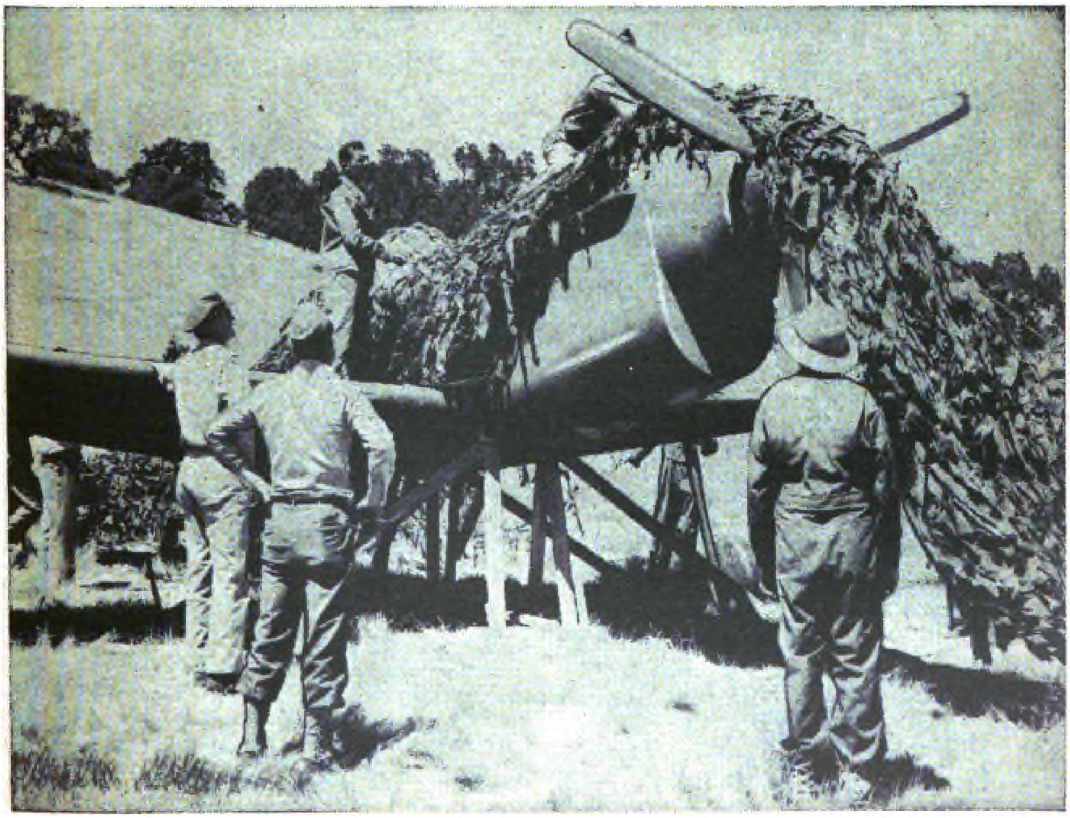


FIGURE 177.—Flat-top where no cover exists. Terraced sides would aid camouflage. Garlands should be woven horizontally.

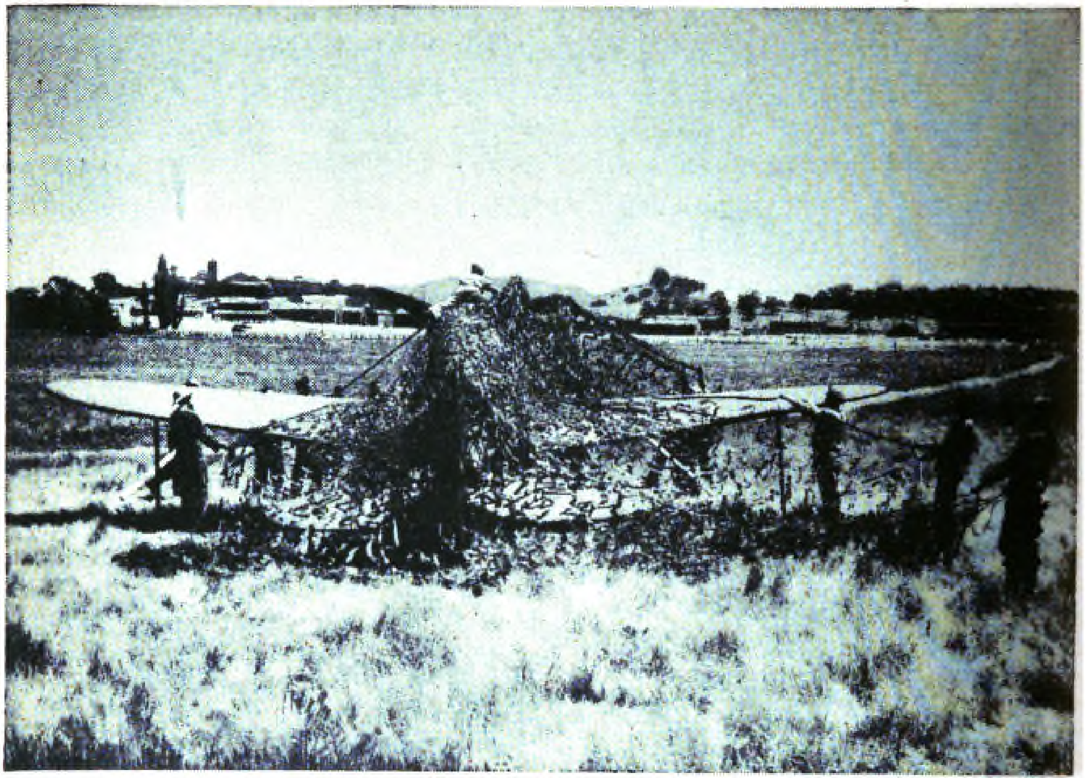


① Rolling out net on airplane. Note that net has been folded so that it will unfold easily.

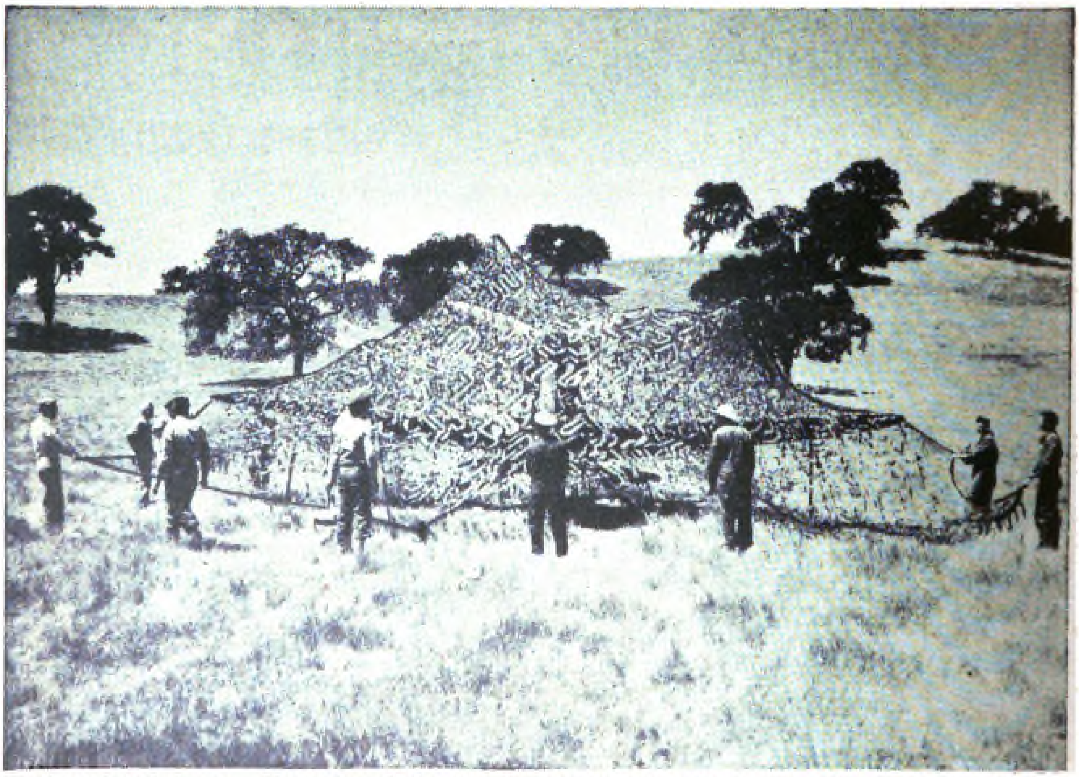


② Net ready to open for stretching.

Figure 178.—Concealing airplane with net.

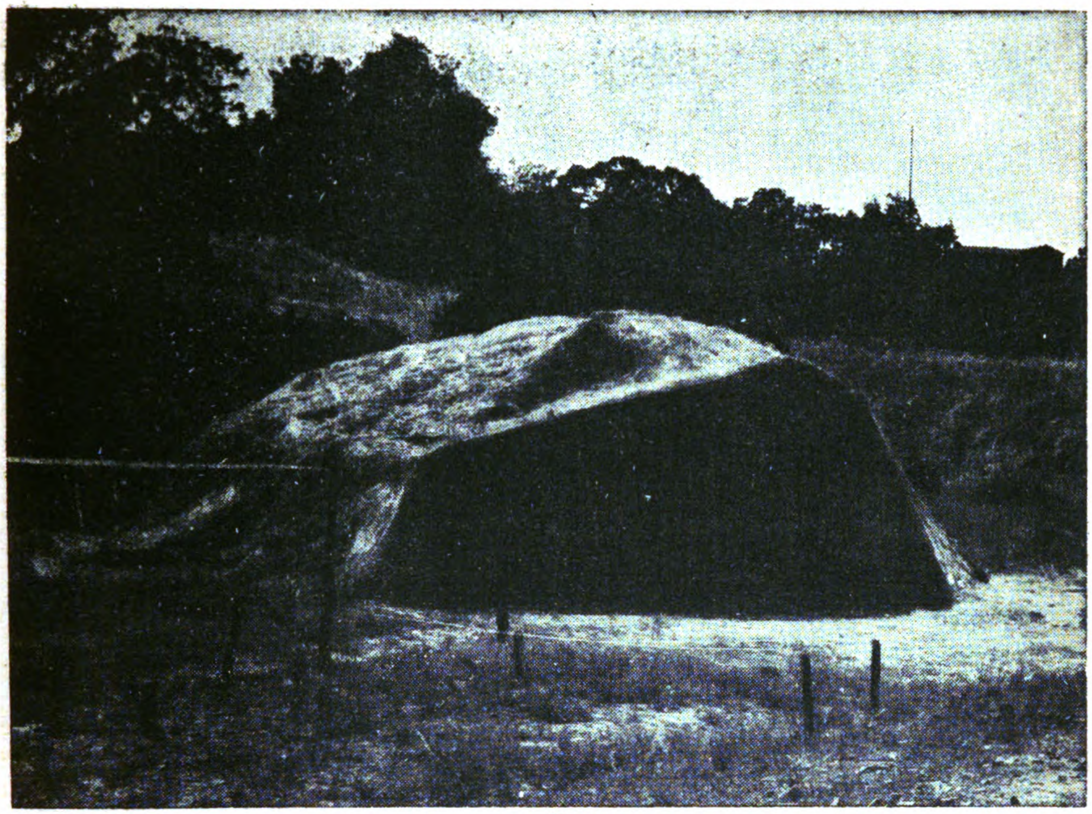


③ Stretching net.

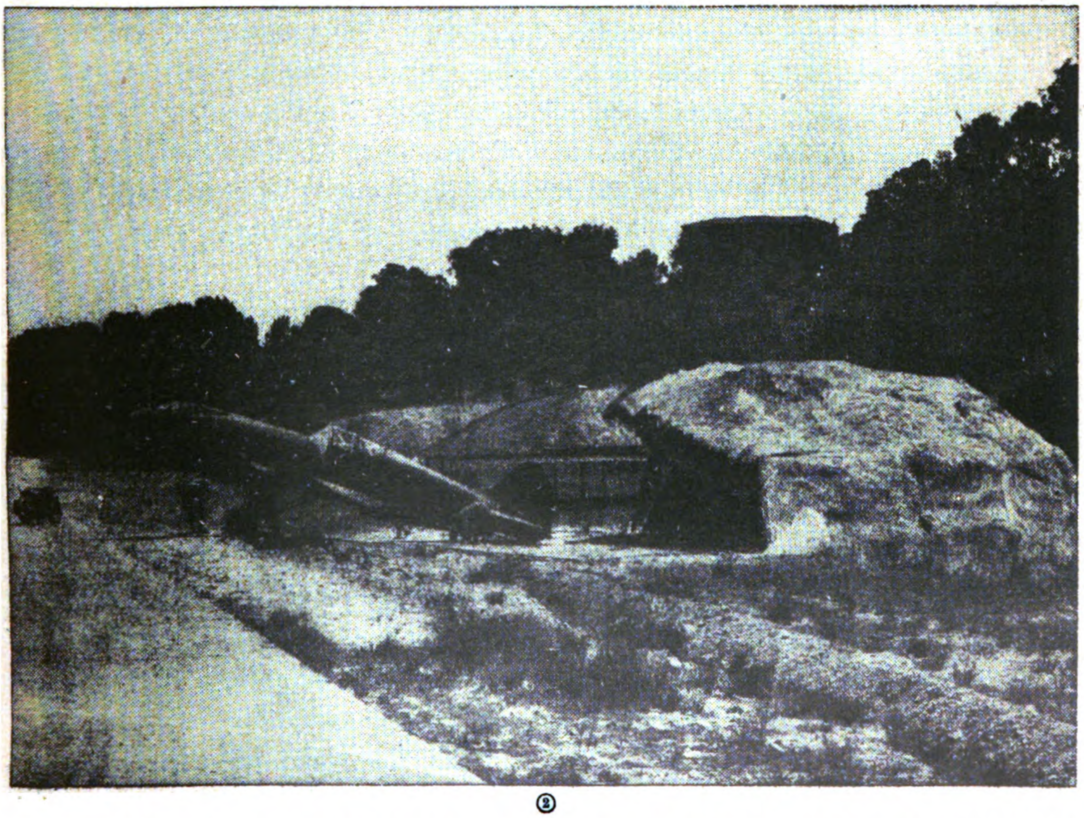


④ Completed drape. Note that light supports keep drape from revealing form by clinging to airplane.

FIGURE 178.—Concealing airplane with net—Continued.



①



②

FIGURE 179.—False strawstack to conceal airplane. Many kinds of deceptive covers can be constructed to resemble features common in the locality.

CHAPTER 15

AIRBORNE ENGINEER AVIATION UNITS—MISSION, TROOPS, EQUIPMENT, AND TRAINING

Paragraph
General 202
Mission 203
Organization 204
Equipment 205
Training 206

202. General.—An airborne engineer aviation battalion is the engineer aviation unit accompanying an airborne or amphibious task force, to provide advance base facilities for troop carrier and air support operations of the Army Air Forces. It is specially organized, trained, and equipped to provide quickly the minimum base facilities necessary for limited operation from an advanced landing field which may be in rear of enemy lines. As an air force engineer unit, it operates under the technical supervision of the task force engineer. It is similar to other engineer aviation battalions, except that it is transported by gliders and cargo airplanes. The mode of transport imposes certain limitations on equipment and, therefore, on organization. Future development of air transport facilities will greatly modify these limitations, allowing for transport of more efficient engineer equipment. The organization and equipment as outlined in this chapter will be for a unit utilizing transport facilities available in 1942.

203. Mission.—*a.* Airborne engineer aviation units are charged with the rapid construction, repair, and maintenance of advanced landing fields initially which, as indicated above, may be in rear of enemy lines. Speed of transport and speed of operation are essential in providing minimum landing facilities for troop carrying transports and gliders and for air support operations.

b. Airborne engineer aviation units may fill bomb craters on concrete, steel, asphalt, wooden, and turf runways; remove from landing areas obstacles which may include mines and crashed airplanes; neutralize small contaminated areas essential to the operation of the field; and provide minimum facilities for servicing aircraft.

c. In case of landings on hostile shores, the light equipment of an airborne engineer battalion can be landed on a beach much more readily than the heavier equipment of the standard battalion. Therefore, the

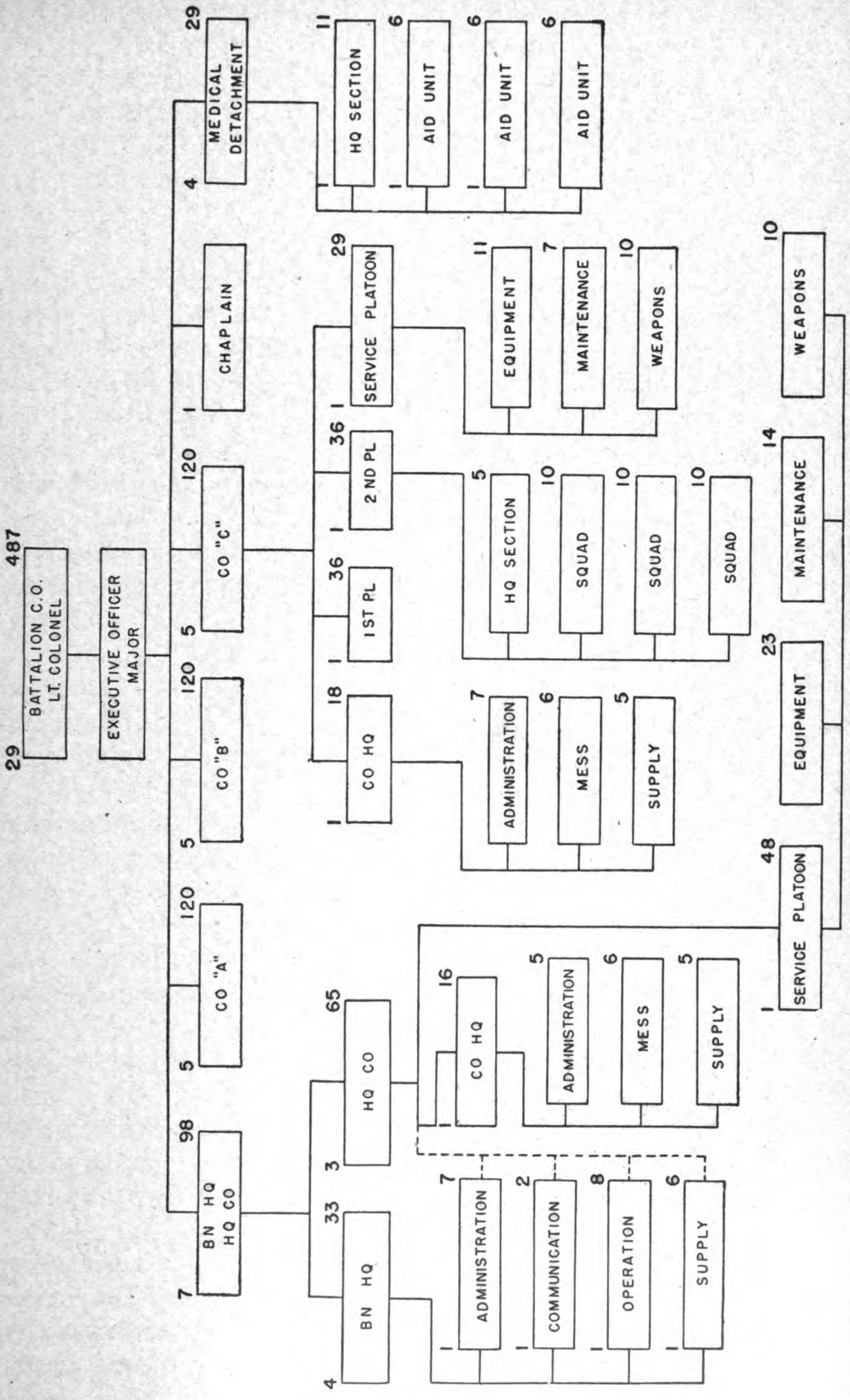

29
BATTALION C.O.
LT. COLONEL
487
EXECUTIVE OFFICER
MAJOR
7
BN HQ
HQ CO
98
5
CO "A"
120
5
CO "B"
120
5
CO "C"
120
1
CHAPLAIN
4
MEDICAL
DETACHMENT
29
4
BN HQ
33
1
ADMINISTRATION
7
1
COMMUNICATION
2
1
OPERATION
8
1
SUPPLY
6
3
HQ CO
65
1
CO HQ
16
ADMINISTRATION
5
MESS
6
SUPPLY
5
1
SERVICE PLATOON
48
EQUIPMENT
23
MAINTENANCE
14
WEAPONS
10
1
CO HQ
18
ADMINISTRATION
7
MESS
6
SUPPLY
5
1
1ST PL
36
1
2 ND PL
36
HQ SECTION
5
SQUAD
10
SQUAD
10
SQUAD
10
1
SERVICE PLATOON
29
EQUIPMENT
11
MAINTENANCE
7
WEAPONS
10
1
HQ SECTION
11
1
AID UNIT
6
1
AID UNIT
6
AID UNIT
6

FIGURE 180.—Organization of an airborne engineer aviation battalion.

airborne battalion sometimes may be used for the initial rehabilitation of airdromes near such landing points.

d. Missions less frequently undertaken include extensive camouflage, construction of elaborate ground installations including disposal areas and access roads, and installation of power systems, field lighting, and gasoline supply systems. These functions will be undertaken only when an advancing engineer aviation battalion is not available to take over the engineer responsibility of the air field.

e. Since combat for self-preservation often may become a primary mission of airborne engineer aviation units, they are trained and equipped for execution of that mission. Nevertheless, aviation engineers are primarily service troops. Although adequately armed for their own security, they should not be used as a combat force in the initial effort of securing a field and reducing enemy defensive installations. An organization once committed to combat finds it difficult to withdraw and commence repair operations.

204. Organization.—The organization of the battalion is shown in figure 180. The battalion is composed of a headquarters and headquarters company, three construction companies, a medical detachment, and a chaplain.

a. Battalion headquarters and headquarters company.—Battalion headquarters and headquarters company consists of seven officers and 98 enlisted men in three platoons: battalion headquarters platoon, company headquarters platoon, and service platoon. (See FM 5-5.)

(1) *Battalion headquarters platoon* consists of a communication section under the battalion adjutant, an administrative section under the battalion personnel officer, an engineering section under the S-3, and a supply section under the S-4.

(2) *Company headquarters platoon* is commanded by a second lieutenant and consists of an administrative section, a mess section, and a supply section.

(3) *Service platoon* is commanded by a first lieutenant and consists of three sections totaling 48 men.

(*a*) The *equipment section* is a pool of road construction equipment and operators for that equipment, used to supplement company construction equipment as deemed necessary by the battalion engineering officer, S-3.

(*b*) The *maintenance section* consists of 14 enlisted mechanics, blacksmiths, and welders trained and equipped for third echelon maintenance of all battalion equipment. These men also are specially trained to augment battalion equipment by repairing captured enemy equipment.

b. Construction company.—The construction company of five officers and 120 enlisted men is the basic task unit. It is commanded by a captain and consists of a company headquarters, two construction platoons, and a service platoon. (See **FM** 5-5.)

(1) *Company headquarters.*—Company headquarters consists of the company commander, a second lieutenant administrative officer, the company administrative section of seven men, a mess section of six men, and a supply section of five men. The company administrative section, headed by a corporal company clerk, operates a communication section with radio communication to battalion and runner and flare communication to platoons.

(2) *Service platoon.*—The tasks assigned companies in the theater of operations often require operation away from the battalion. The service platoon is, therefore, provided to maintain the equipment when the company is engaged in a separate operation. It consists of an equipment section, a maintenance section, and a weapons section, a total of one officer and 29 enlisted men. The equipment section is the equipment pool to which are assigned all construction equipment operators. The maintenance section is responsible for repair and servicing of all company equipment and for salvage and repair of captured enemy construction equipment. The weapons section is an antiaircraft section of two .50 caliber guns, air-cooled, to provide protection to the company.

(3) *Construction platoon.*—Each construction platoon, one officer and 36 enlisted men, consists of a headquarters and an operating section of three squads. The headquarters consists of a first lieutenant, a staff sergeant, a bicycle messenger, a mine detector operator, an electrician for lighting night operations, a truck driver, and a communication specialist with signal panels and flares.

(4) *Construction squad.*—The construction squad consists of two noncommissioned officers (a sergeant and a corporal) and eight privates. Each is trained in an engineer specialty to form a well balanced, all around unit capable of undertaking any minor engineer task. The armament of the squad includes eight M1 rifles; a submachine gun; and one 1903 rifle, antitank, with M9 grenades.

c. Medical detachment.—The medical detachment consists of four officers and 29 enlisted men. They are organized, trained, and equipped to set up field aid stations of an officer and six enlisted men with each construction company and a headquarters aid station of a dentist and eleven enlisted men. The training of medical personnel for operation of field aid stations is the responsibility of the battalion surgeon (see **FM** 8-5).

205. Equipment.—*a.* Engineer tools and equipment are of necessity light and small. Included are air compressors with saws, tamps, and drills; light crawler tractors with bulldozers; asphalt repair equipment; electric lighting sets for night lighting of areas under repair; leaning wheel towed graders; gasoline motor driven hammers and chain saws; mine detectors; road material mixers; sump pumps; compaction rollers; scrapers; rooters; rubber-tired tractors; oxyacetylene welding and cutting equipment; water supply equipment, and squad carpenter, pioneer, demolition, and pipe fitting sets.

b. The medical detachment has standard medical equipment as provided engineer aviation battalions but in somewhat greater quantities. Each company, when operating separately, can establish a unit aid station immediately after landing.

c. Communication equipment is limited to radio from company to battalion and from battalion to task force headquarters, signal panels, signal flares, and bicycle messengers.

d. Transportation is sufficient for administration and operation but is not provided for equipment or personnel. The total includes only nineteen ¼-ton, 4 x 4 trucks, seven 2½-ton, 6 x 6 dump trucks, and one ¾-ton carryall (rear echelon). Troops must make every effort upon landing to gain additional motor transport by requisition or by capture of enemy transportation.

e. Armament of a battalion consists of carbines, rifles, submachine guns, and .50 caliber antiaircraft guns. The battalion is trained for combat as infantry.

206. Training.—*a.* The training of airborne aviation engineers includes that outlined in chapter 4 for all engineer aviation battalions. Indoctrination first with the operational needs of air force units and later with requirements of other units in the airborne command is necessary. It is highly desirable to have intimate contact with air force personnel, equipment, facilities, and installations. Combined training with airborne ground units likewise is necessary. Training periods allocated to combined operations are essential.

b. In addition to training outlined in chapter 4 emphasis should be placed on special training for officers in the following:

(1) Logistics of emplaning and deplaning troops, equipment, and supplies.

(2) Planning and execution of tactical operations, particularly in defense of airdromes, requiring precise coordination with air forces, parachute troops, and supporting arms.

(3) Communication with supporting aviation and task force headquarters.

(4) Administration, supply, and evacuation of units when normal transportation facilities are lacking.

c. Troops should be specially trained in—

(1) Emplaning and deplaning, including loading and securing supplies and equipment.

(2) Technique of organizing and executing missions to be performed immediately upon landing, with emphasis upon repair of landing areas.

(3) Repair and operation of captured enemy weapons, transportation, and equipment.

(4) Technique of operating all organic weapons. It is essential that all individuals be proficient in use of the rifle and that adequate placements be trained for gun crews.

(5) Communication with supporting aircraft with emphasis on methods of identifying themselves. (See FM 31–30.)

APPENDIX I

REPORT OF AIRDROME SITE RECONNAISSANCE

Designation of airdrome____
Type and number of aircraft to be accommodated__________________
Other special requirements in information furnished______________
Date of reconnaissance____

1. Description and location.
a. Map references and drawings.
b. Geographic position.
(1) Latitude and longitude.
(2) State, county, section, township, and range.
(3) Elevation above sea level.
(4) Local magnetic variation.
c. General description.
(1) Nearby towns.
(*a*) Direction and distance thereto.
(*b*) Population.
(*c*) Accommodations available as billets.
(2) Character of surrounding community.
(*a*) Agricultural, industrial, etc.
(*b*) Intentions of inhabitants, if known.
(3) Physical features of site.
(*a*) Dimensions in various directions (sketch).
(*b*) Natural condition of surface.
(*c*) Natural drainage; general slope of ground.
(*d*) Obstruction on approaches.
    1. Location of obstruction.
    2. Nature of obstruction.
    3. Estimate of removal of obstruction.

2. Meteorological data.—(Consult civil authorities and natives and observe vegetation.)

a. Monthly rainfall records and storm intensity-duration data.
b. Monthly temperature records.
c. Direction and velocity of prevailing winds. (Observe vegetation and look for evidence of drifting sand.) Wind rose. (See figs. 181 and 182.)

d. Special climatic features (fog, dust, storms, smoke, cyclonic disturbances, ice formations on runways).

3. **Hydrological features** (where pertinent).

a. Stream flow records.

b. Flood conditions and flood control works.

c. General description of geological formation.

d. Information on underground water supply.

4. **Soil investigation** (see app. III).

a. Ground water elevation.

b. General composition of soil (percentage of clay, sand, gravel, etc.).

c. General classification of soil (see app. III, secs. I–VI incl.).

d. Bearing ratio of soil.

e. Drainage characteristics.

f. Frost heaving tendency.

g. Shrinkage and expansion characteristics.

h. Notes on soil profile.

i. Samples (100 lb.) of predominant soil or soils for field laboratory examination.

5. **Drainage.**

a. Other conditions affecting drainage.

(1) Data on outlet conditions.

(2) Infiltration capacity of soils.

b. Type of drainage believed necessary.

6. **Grading.**

a. Profiles of proposed runways and taxiways.

b. Estimate of runway and taxiway grading.

c. Estimate of grading for buildings and service roads.

7. **Pavement.**

a. Treatment of subgrade, if any.

b. Flexible or rigid types.

c. Base courses.

(1) Number of layers and thickness.

(2) Methods of construction.

d. Surface course.

(1) Type and thickness.

(2) Methods of construction.

e. Availability of construction materials.

f. Samples (100 lb.) of gravel, sand, rock deposits for field laboratory examination.

8. **Camouflage considerations.**

a. Landmarks.

b. Natural foliage and cover.

c. Terrain irregularity and pattern.

9. Transportation facilities.

a. Roads. (Examination of existing roads often gives valuable clues for design of runways.)

(1) Identification of each road concerned.

(2) Type of surface and condition.

(3) Thickness of surface and base courses.

(4) Usable width.

(5) Limiting grades.

(6) Bridges and culverts—locations, dimensions, capacity, condition.

(7) Priority and nature of repairs or new construction.

(8) Materials available locally.

b. Railroads.

(1) Name and location.

(2) Nearest freight office and distance from site.

(3) Gage and rail weight.

(4) Character of roadbed.

(5) Capacity of bridges.

(6) Length and cost of spur line to site.

(7) Types and condition of rolling stock.

(8) Daily tonnage capacity.

(9) Remarks.

c. Waterways.

(1) Name and location.

(2) Channel depths.

(3) Nature and condition of floating plant available.

(4) Length and width of wharves.

(5) Railroad and highway connections.

(6) Transit sheds.

(7) Unloading equipment (type and capacity).

(8) Adjacent storage (sq. ft.).

(9) Remarks.

10. Utilities.

a. Water supply (for additional information, see par. 210, FM 5-10).

(1) Location and source (well, spring, pond, etc.).

(2) Rate of flow in gallons per day.

(3) Motive power (gravity or pump).

(4) Turbidity, contamination, taste, color, and odor.

(5) Method of treatment.

(6) Storage and distribution system.

(7) Size line, static pressure, and flow capacity at various heads at point of connection of proposed supply line to existing supply.

(8) Length and size of proposed supply line from point of connection to point of discharge.

(9) Difference in elevation between point of connection and location of pumping plant, ground storage tank, or other proposed point of delivery.

(10) Limit of quantity that may be taken from existing system in order to maintain adequate pressure in vicinity of connection.

(11) Wells (dug, driven, drilled, bored).

(*a*) Size and depth of well and distance to water when pumped to capacity.

(*b*) Normal capacity.

(*c*) Can turbine pumps be used directly from well to distribution system?

b. Electric power.

(1) Name and location of company.

(2) Distance and direction to nearest transmission line or substation of adequate capacity.

(3) Details of power system (see table XXIX).

TABLE XXIX.—*Details of power system*

Prime movers	Generators	Transmission lines
Type-------------------- (Steam, internal combustion) Fuel------------------ Amount on hand------- Feed------------------ Hp-------------------- Lubricants------------- (Kind and amount) Water supply----------- (Character and amount) General condition-------	Type------------------ (A-c or d-c) Number of machines------ Kva--------V--- ------ Kw-------------------- Amps------------------ Power factor------------ Frequency--------------- Rpm------------------- Hp--------Mfg--------- General condition-------- Switchboard Instruments--------- Interconnections---- Condition-----------	Type------- ------ (2 wire, 3 wire Edison) (1, 2, 3, phase a-c) Current---- --V ------- (A-c or d-c) Conductors------------- (Size and material) Location--------------- (Poles or underground) Transformers----------- Substation-------------- (Transformer or synchronous converter) Electrical supplies-------

c. Telephone and telegraph.

(1) Location of nearest installations.

(2) Operating company.

(3) Number of wires and circuits: From ---------- to ----------.

(4) Condition of system.

d. Sewage disposal.

(1) Independent or new system.

(*a*) Distance to disposal point, name, quantity of flow, or size of water body, and whether water is used for drinking, bathing, etc.

(*b*) Treatment to be provided raw sewage.

(*c*) Where streams or other bodies of water are not available for disposal purposes, give information as to soil absorption, possibility of ground water contamination, etc.

(*d*) Remarks as to probable type and extent of treatment required.

(2) Utilizing existing system.

(*a*) Length and size of connecting main required.

(*b*) Will any existing sewers have to be enlarged?

(*c*) Is existing sewage treatment plant of sufficient capacity to handle increased load? Type and capacity of existing plant.

(*d*) Must sewage be pumped in order to deliver it to existing system or disposal works? If so, estimate probable pumping cost.

(*e*) Remarks.

e. Cold storage.

(1) Cubage.

(*a*) Chill.

(*b*) Freezing.

(2) Type of condensers.

(3) Ice making capacity.

(4) Type of power source.

11. Construction materials and equipment.

a. Standing timber.

b. Lumber yards.

(1) Location.

(2) Quantities.

(3) Cutting machinery.

c. Hardware stores.

(1) Location.

(2) General description of stock.

d. Gravel pits.

(1) Location.

(2) Machinery at pit.

(3) Daily capacity cost.

e. Brickyards.

f. Other building materials (cement, asphalt, tar, roofing, etc.).

g. Road machinery.

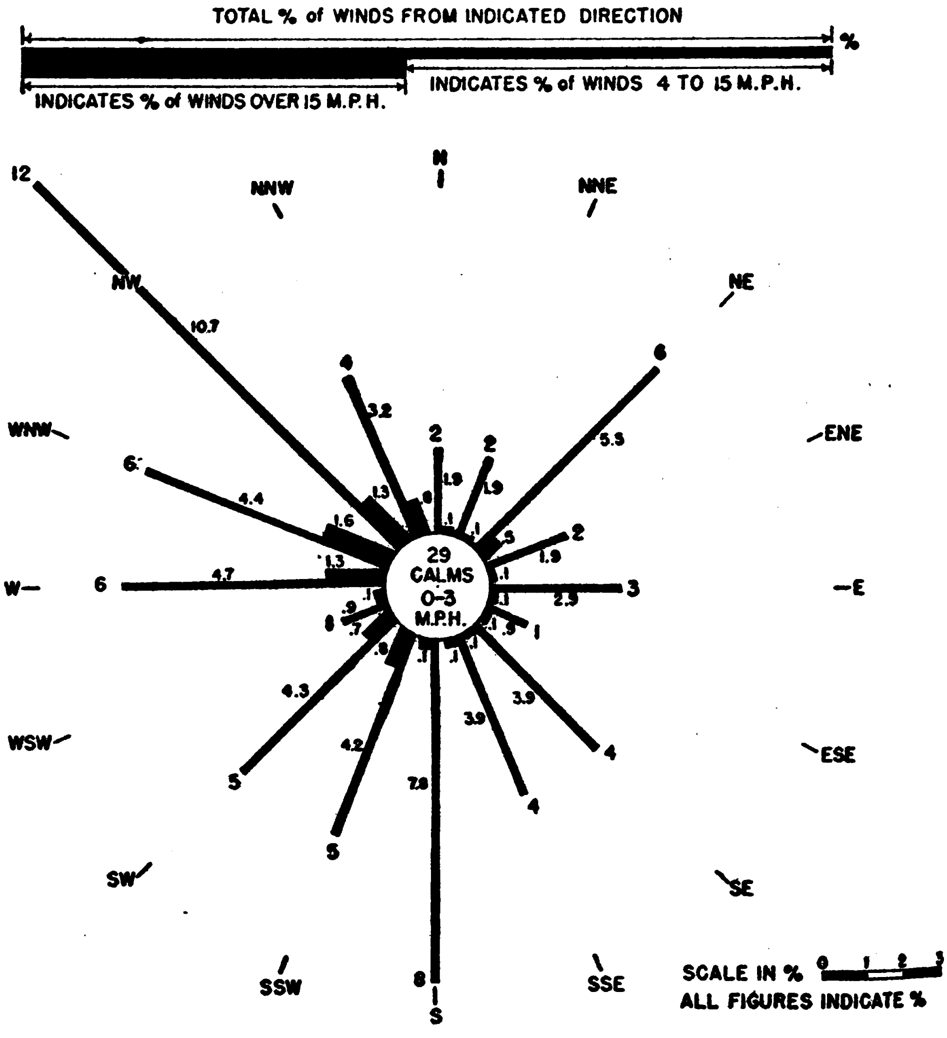
(1) Make, size, number.

(2) Location.

12. **Summary.**

13. **Estimate of construction labor, materials, and time.**

14. **Recommendations.**



AIR BASE LOCATION

SURFACE WIND VELOCITY OVER A PERIOD OF 9 YEARS. U.S.WEATHER BUREAU[✓ (AIR BASE)](CITY)STATION

REMARKS: The above information covers a period ending with 1938. CHECK WHICH

FIGURE 181.—Wind rose.

STATION ____________________ ELEVATION ___ ANNUAL ____________ PERIOD 1930 ________

DIR. / M.P.H.	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	TOTAL OBS	PERCENT
4-15	1835	1578	4307	1555	2113	1147	2973	3332	6155	3289	3372	806	3735	3456	8448	2533	50634	65
16-31	94	65	98	49	20	6	17	33	178	256	170	103	742	1342	1545	316	5034	6
32-47	1		2	1				1			6	4	36	57	57	3	168	*
OVER 47											1		1				2	*
CALM 0-3																	22860	29
TOTAL O.B.S.	1930	1643	4407	1605	2133	1153	2990	3366	6333	3545	3549	913	4514	4855	10050	2852	78698	
29	2	2	6	2	3	1	4	4	8	5	5	1	6	6	12	4		100

* INDICATES LESS THAN ½ OF 1%

MAXIMUM WINDS (M.P.H.)

STATION ____________________ ELEVATION ________ YEARS OF RECORD ____________

MONTH / YEAR	JAN.	FEB.	MAR.	APR.	MAY.	JUN.	JUL.	AUG.	SEPT.	OCT.	NOV.	DEC.	MAXIMUM
1930			WNW 40 20 HR	WNW 46 12 HR	NW 40 20 HR						NW 42 22 HR	NW A 42 19 HR A	46
1931	W 34 6 HR	NW 37 13 HR	W 34 13 HR	NW 46 17 HR	WNW 36 13 HR		SW 52 15 HR	W 35 17 HR			SW 38 4 HR	W 40 16 HR	52
1932	W A 36	W 39	W 50	W 32									50
1933		WNW A 40 7 HR A	WNW 33 14 HR					ENE 36 17 HR			W 40 1 HR	WNW 38 14 HR	40
1934	NW A 40 1 HR A	WNW 38 13 HR	WNW 38 18 HR			W 42 23 HR				WNW 44 15 HR		NW 34 14 HR	44
1935	NW 43 15 HR		NW 35 16 HR	WSW 35 22 HR	W 38 11 HR							WNW 36 19 HR	43
1936	NW 40 1 HR	WNW 34 15 HR	WNW 39 14 HR	W 32 14 HR	NW 39 16 HR	WNW 35 16 HR					WNW 43 16 HR		43
1937		WNW 34 23 HR		WNW 32 17 HR								W 33 11 HR	34
1938	W 38	W 35	W 38	WSW 33								WNW 33	38
MAXIMUN	43	40	50	46	40	42	52	36		44	43	42	52.

FIGURE 182.—Period summary by combined velocity groups.

APPENDIX II

AIRCRAFT CHARACTERISTICS AND MARKINGS

Paragraph
Purpose 1
Operational requirements of aircraft 2
Training material 3
Means of identification 4
Distinctive markings 5
Model designation of aircraft 6
Types of aircraft 7

1. **Purpose.**—This appendix has two purposes: to serve as an aid in the identification of U. S. Army aircraft, and to provide information on current models for which it may be necessary to design suitable accommodations.

2. **Operational requirements of aircraft.**—*a. Stalling speed.*—Aircraft in flight are supported and controlled by the flow of air over he wing and tail surfaces. When the speed of the airplane falls below a certain critical point it stalls, that is, the airplane is inadequately supported and does not respond to the controls. The stalling speed is relative to the air-flow and has no reference to ground speed. When an airplane takes off or lands into the wind the air speed is greater than the ground speed. Consequently, the necessary ground run is shortened. Modern aircraft design tends toward greater wing loads which make necessary higher landing speeds. These factors create a need for hard surfaced runways of considerable length.

b. Landing.—(1) When a pilot wishes to land, he maneuvers his aircraft into position downwind of the runway and, closing his throttle, puts his aircraft into the proper gliding angle. As he nears the ground he flattens his glide and continues to raise the nose until the airplane stalls. If there is any obstacle near the end of the runway over which he must pass, he must land farther in the runway as any attempt to steepen his angle of glide merely increases his speed so he has to travel further before reaching the stalling point.

(2) When the aircraft first touches the ground it is still partially airborne. Any unevenness, especially an abrupt change of slope, tends to bounce the airplane into the air and cause it to land heavily farther on. As the aircraft runs along its speed is rapidly reduced and its weight is transferred to the two main wheels. If these are checked suddenly by a soft spot in the runway the airplane may tip onto its nose or wing.

c. Take-off.—When an airplane takes off, stalling speed must be exceeded in order to leave the ground. A considerably greater rate must be reached before the airplane can climb. These phases require a long, straight stretch of clear ground, hence the cleared zones in extension of runways.

3. Training material.—Aviation engineer personnel, especially air guards, should be able to recognize aircraft as friendly or hostile from identification of type and model. Four hours are allotted to aircraft identification in the suggested training program; much additional informal study should be promoted. Useful instructional aids of many types are available, including the following:

Field Manual

FM 30-30, Identification of U. S. Aircraft.

Training Bulletins (Infantry School)

TB No. 132, Identification of Friendly Aircraft (Army Ground Forces).

TB No. 143, Silhouettes, U. S. Army Air Corps (Army Ground Forces).

Training Films

TF 1-258, General Characteristics and Types of U. S. Military Airplanes.

TF 1-259, Distinguishing Features of U. S. Military Airplanes.

Film Strips

FS 1-31, Preliminary Study of the Identification of Aircraft.

FS 1-38, Points to Look for in Identification of Aircraft.

FS 4-2, Identification of Aircraft.

4. Means of identification.—Three factors assist in the classification and identification of aircraft:

a. Characteristic visible features including type of construction and distinctive markings. Most airplanes have some peculiarity in structure which aids in determination of model. Visible features to study in identification are wings, engine, fuselage, and tail.

b. Characteristic methods of operation and maneuver, indicative of general type and mission.

c. Characteristic sound, ordinarily indicative only of general type, approximate number, and direction of flight of airplanes. Acute observers may be trained to make more specific identification on the basis of sound alone.

5. Distinctive markings.—The identifying insignia of United States aircraft is the white five-pointed star superimposed on a circular blue field. The star insignia appears on the upper left and lower right wing tips, and on the sides of the fuselage about midship. The rudder is painted a dark olive drab, which is the same color as the upper and side portions of the airplanes.

6. Model designation of aircraft.—*a.* Type designation is indicated by a letter or letters corresponding to the function of that class.

Type	*Designation*
Bombardment (light)	A
Bombardment (medium and heavy)	B
Fighter	P
Observation	O
Observation amphibian	OA
Reconnaissance (photographic)	F
Training (primary)	PT
Training (basic)	BT
Training (advance)	AT (BC)
Transport (cargo and personnel)	C
Autogiro	G
Glider (cargo)	CG
Glider (training)	TG
Rotary wing	R

b. Arabic numerals following the letters indicate the specific model. Letter suffixes differentiate later and improved versions of a model.

c. The prefixes, X, Y, and Z before a model designation indicate the respective stages—experimental, service test, and obsolete—in the model's service life. Standard models have no prefix.

d. The designation B–17F illustrates the use of the above symbols. The B indicates heavy bombardment type; the –17 designates the Boeing known as the "Flying Fortress", and the F marks it as sixth in the series of improvements on the original model. By the absence of a prefix before the B, it is known to be a standard model in production and in service.

7. Types of aircraft.—*a.* The principal combat types in the U. S. Army are as follows:

(1) *Fighter airplanes* are fast, highly maneuverable craft designed for aerial combat. Some models can climb almost vertically. Fighters normally operate at high altitudes and in squadron formation. The sound is high pitched and varies extremely in tone and volume during such maneuvers as climbing and diving.

(2) *Bombardment* airplanes are classified as heavy, medium, and light. The sounds are generally characterized by a fairly deep pitch, moderately heavy volume, and steady tone and rhythm.

(*a*) *Heavy and medium bombers* are designed to carry heavy bomb loads great distances. En route to and from their objectives they operate in formation at high altitudes.

(*b*) *Light bombardment* airplanes are designed to attack material objectives of light construction, airdromes, routes of communication and supply, and personnel concentrations. These are fast, maneuverable craft of medium size. Since light bombers operate at low altitudes and are susceptible to small-arms fire, troops must be able to identify friendly airplanes quickly and accurately.

(*c*) *Dive bombers* are designed to launch a heavy bomb at a well defined target by diving steeply from a considerable height. Necessary special construction makes these airplanes relatively slow and easy prey for fighters. Normally they are used to support advancing ground troops in zones where friendly fighters dominate the air.

(3) *Observation* airplanes are designed to carry two men at a slow rate low over friendly territory. Besides observation, their mission includes communication and artillery fire adjustment. Ground troops should be able to recognize this type instantly.

b. Transport and training airplanes are the principal noncombat types employed by the Army.

(1) *Transport* airplanes are designed to move loads of personnel and supplies, normally over friendly territory. They are large slow craft, fly at moderate heights, and resemble peacetime commercial airliners.

(2) *Training* airplanes rarely will be seen in the theater of operations.

TABLE XXX.—*Dimensions of aircraft (for designs of taxiways and revetments)*

Model	Weight (gross loaded)	Wing span	Length (over-all)	Height (at rest)	Height of wing tips	Wheel span center to center of tires
P-38	15, 400	52'0"	37'11"	12'0"	----------	16'6"
P-39C	7, 500	34'0"	29'9"	9'4"	5'1"	11'5"
P-40E	7, 900	37'4"	31'9"	10'6"	5'6"	8'3"
P-47B	12, 400	40'10"	35'4"	12'8"	5'10"	15'8"
P-51	8, 800	37'0"	32'3"	10'2"	----------	----------
A-20A	20, 600	61'4"	47'7"	15'10"	9'5"	----------
A-31	15, 500	48'0"	40'0"	12'10"	----------	----------
O-47A	8, 500	46'4"	33'3"	12'2"	----------	----------
O-49	3, 300	51'0"	33'2"	9'4"	8'0"	6'7"
O-52	5, 600	40'11"	26'5"	9'9"	8'0"	----------
OA-9	7, 900	49'0"	38'4"	12'0"	----------	----------
B-17	48, 700	103'10"	67'11"	15'5"	----------	21'2"
B-17E	53, 000	103'10"	73'10"	19'1"	----------	21'2"
B-18A	30, 000	89'6"	56'9"	15'1"	8'3"	18'0"
B-24	46, 100	110'0"	63'9"	18'8"	----------	----------
B-25	27, 800	67'0"	51'5"	15'11"	9'0"	19'6"
B-26	31, 000	65'0"	56'0"	19'10"	----------	21'11"
C-39	21, 000	85'0"	61'6"	18'8"	----------	18'0"
C-40	9, 200	49'6"	36'4"	9'11"	----------	13'6"
C-45	8, 600	47'8"	34'3"	9'4"	5'7"	13'0"
C-46	45, 000	108'0"	69'0"	19'6"	----------	21'2"
C-49	25, 200	95'0"	64'0"	17'0"	8'10"	18'5"

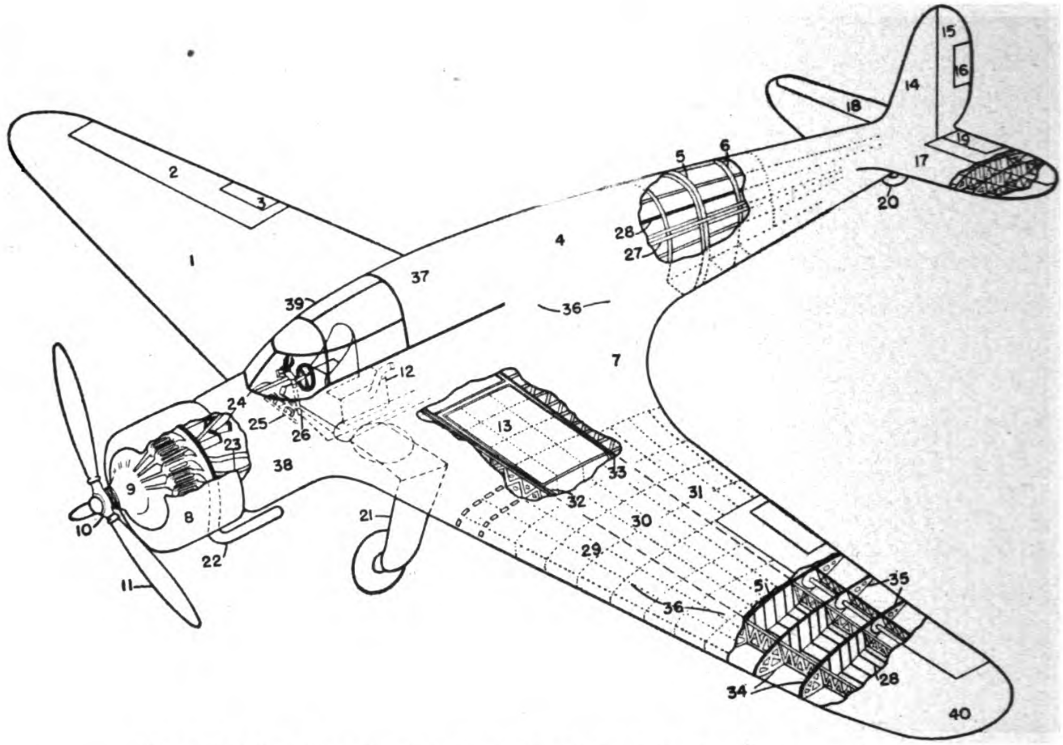

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FIGURE 183.—Principal structural units of single engine airplane.

1. Wing.
2. Aileron.
3. Aileron tab.
4. Fuselage.
5. Frame or bulkhead.
6. Intermediate frame.
7. Fairing.
8. Engine cowl.
9. Engine.
10. Propeller hub.
11. Propeller blade.
12. Oil tank.
13. Fuel tank.
14. Vertical fin.
15. Rudder.
16. Rudder tab.
17. Stabilizer.
18. Elevator.
19. Elevator tab.
20. Tail wheel.
21. Retractable landing gear.
22. Exhaust collector ring.
23. Fuel and oil lines.
24. Engine controls.
25. Rudder control.
26. Elevator and aileron control.
27. Longeron.
28. Stringer.
29. Leading edge.
30. Interspar section.
31. Trailing edge.
32. Front spar.
33. Rear spar.
34. Nose ribs.
35. Aileron ribs.
36. Metal skin.
37. Cabin.
38. Accessory cowl.
39. Pilot's inclosure.
40. Wing tip.

Table XXXI.—*Characteristics of aircraft (useful in visual identification)*

Model	Type	Engines	Special features	Remarks
P-38 (fig. 184)	Midwing fighter	Two, liquid-cooled	Tricycle landing gear	Twin tail booms.
P-39C (fig. 185)	Low wing fighter	One, liquid-cooled	Tricycle landing gear	Long pointed nose.
P-40E (fig. 186)	Low wing fighter	One, air-cooled	May carry bomb	Sharp nose; conspicuous air-scoop.
P-47B (fig. 187)	Low wing fighter	One, air-cooled	Four-bladed propeller	Blunt nose; stubby body.
P-51 (fig. 188)	Low wing fighter	One, liquid-cooled	Wing flaps	Square wing tips.
A-20A (fig. 189)	High wing attack bomber.	Two, air-cooled	Tricycle landing gear	Underslung nacelles beyond trailing edge of wing.
A-31 (fig. 190)	Midwing dive bomber.	One, air-cooled	Wing flaps	Square wing tips. Outer ends crook forward.
O-46A (fig. 191 ①)	Parasol wing observation.	One, air-cooled	External braces; fixed landing gear.	Round trailing edge wings.
O-47A (fig. 191 ②)	Midwing observation.	One, air-cooled	Carries three	Long conspicuous cabin.
O-49 (fig. 191 ③)	High wing observation.	One, air-cooled	Fixed landing gear	Long straight wings.
O-52 (fig. 191 ④)	High wing observation.	One, air-cooled	Modernized O-49	Single wing strut
OA-9 (fig. 191 ⑤)	High wing observation.	Two, air-cooled	Amphibian gear	Flying boat; wing floats.
B-17 (fig. 192 ①)	Low wing heavy bomber.	Four, air-cooled	Gun turrets each side and under fuselage rear of wings.	Broad, tapering wings.
B-17E (fig. 192 ②)	Low wing heavy bomber.	Four, air-cooled	Same as B-17 plus tail gun.	Very large tail surfaces.
B-18A (fig. 194 ①)	Midwing medium bomber.	Two, air-cooled	Modified nose (undercut)	Elliptical wing tips.
B-24 (fig. 193)	High wing heavy bomber.	Four, air-cooled	Tricycle landing gear	Twin oval tail fins.
B-25 (fig. 194 ②)	Midwing medium bomber.	Two, air-cooled	Tricycle landing gear	Long thin nose; twin rudders.
B-26 (fig. 194 ③)	Midwing medium bomber.	Two, air-cooled	Four-bladed propellers; tricycle landing gear.	Long tapered nose.

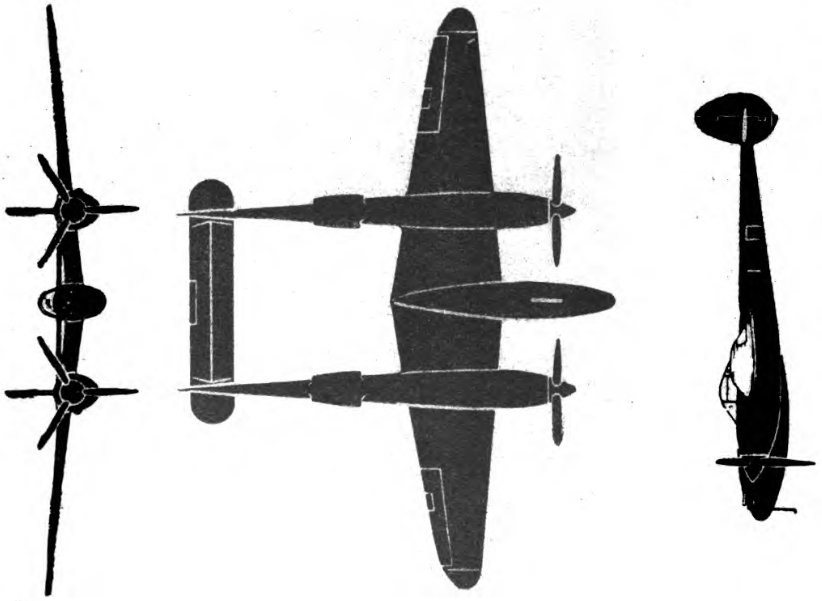


FIGURE 184.—Lockheed P-38 "Lightning."

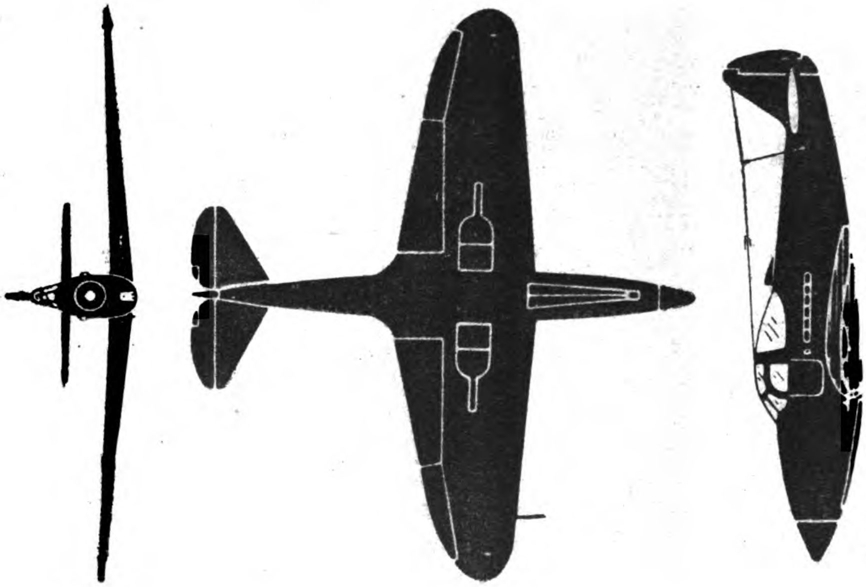


FIGURE 185.—Bell P-39C "Airacobra."

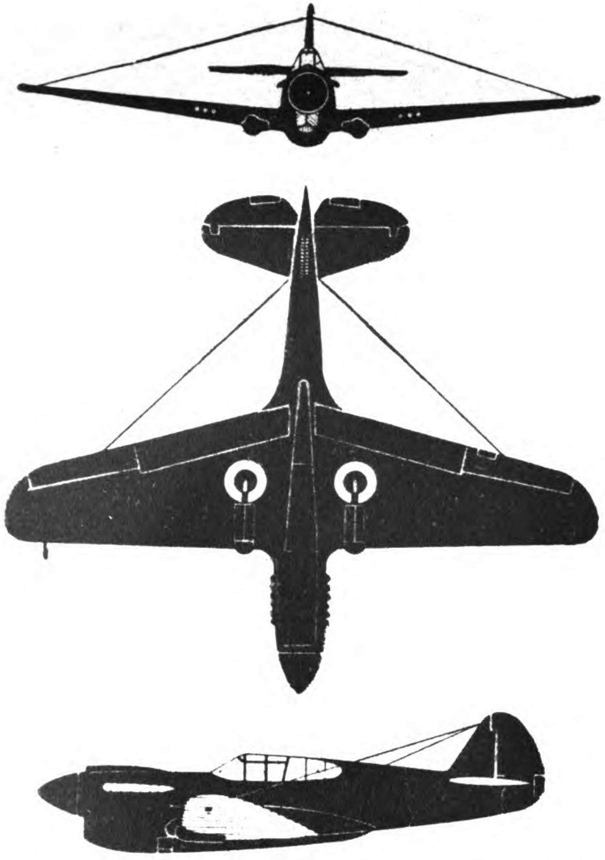


FIGURE 186.—Curtiss P-40E "Tomahawk."

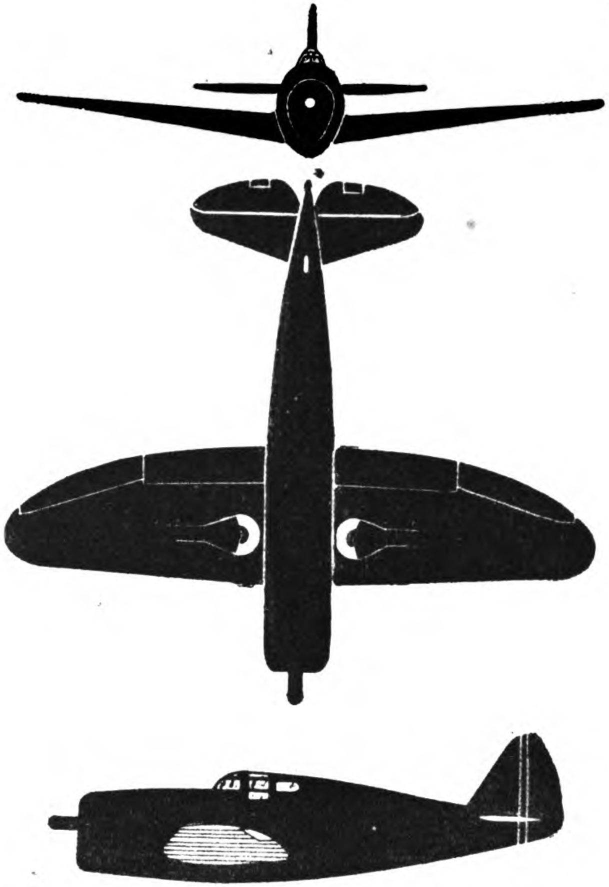


FIGURE 187—Republic P-47B "Thunderbolt."

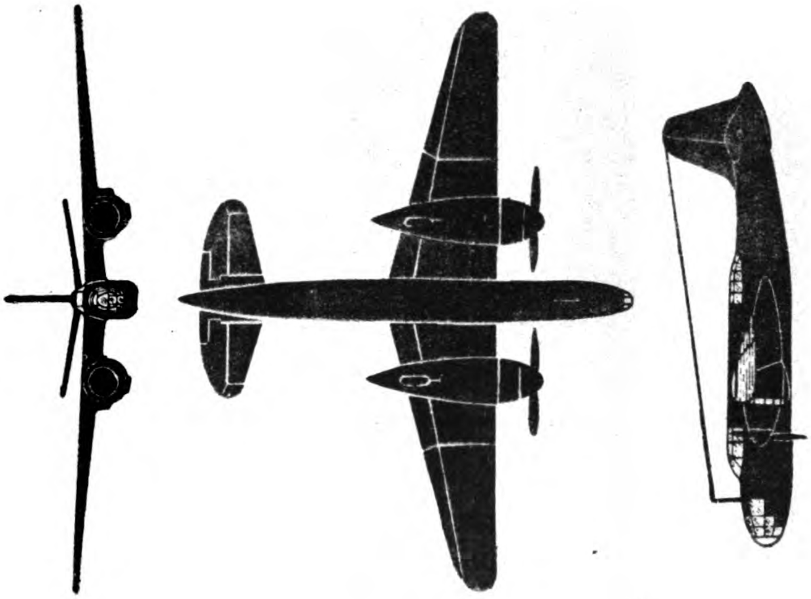


FIGURE 189.—Douglas A-20A, light bomber.

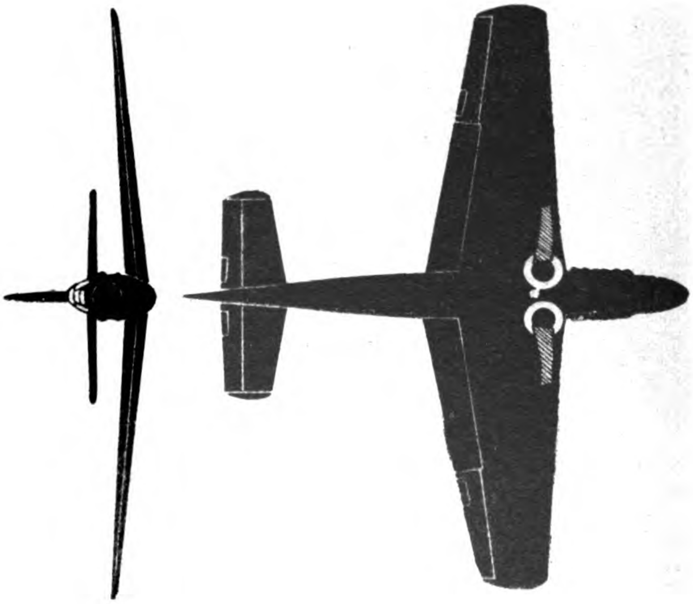


FIGURE 188.—North American P-51 "Mustang."

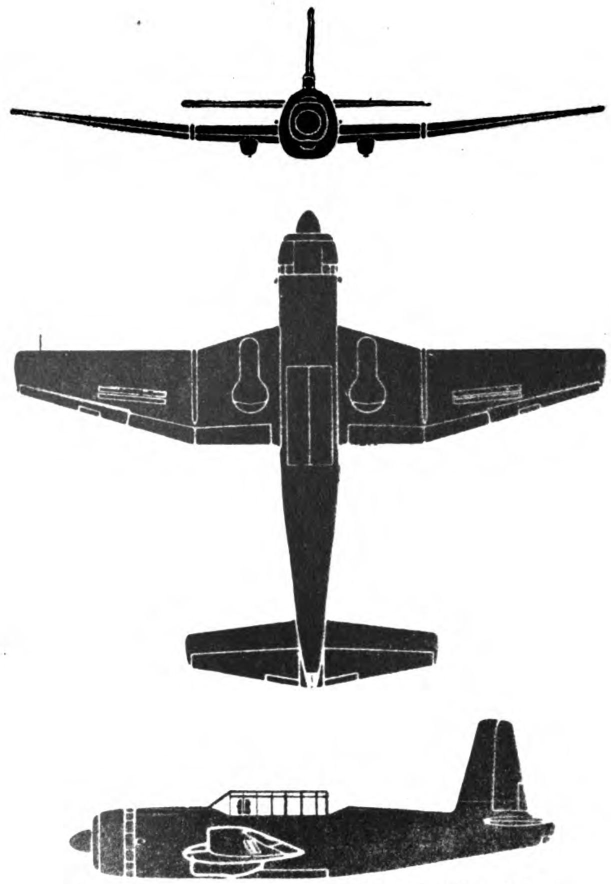


FIGURE 190.—Vultee A-31, dive bomber.

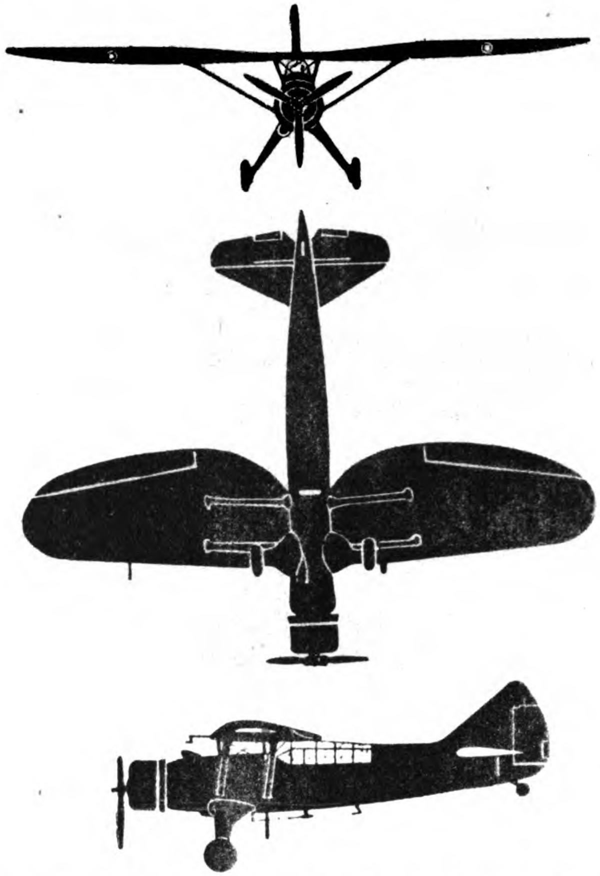
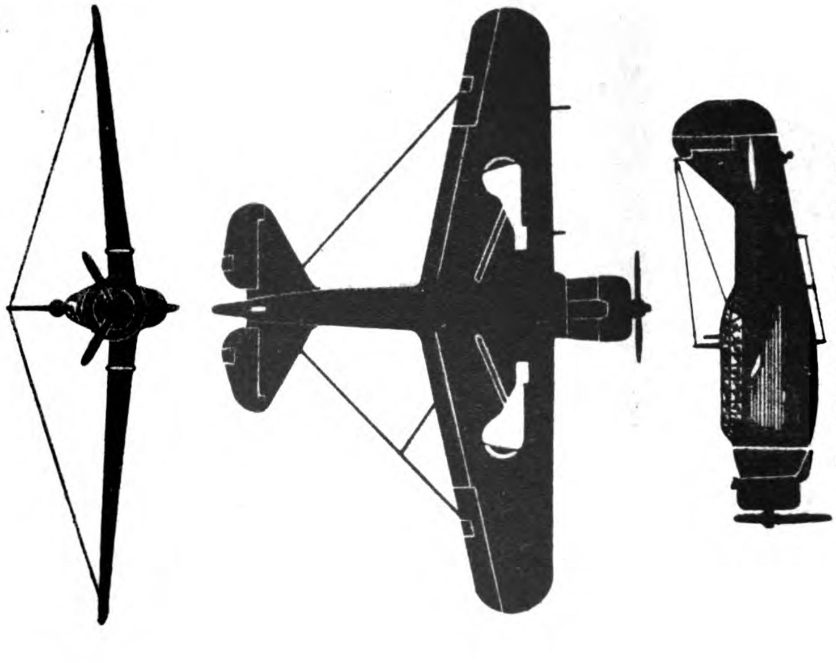
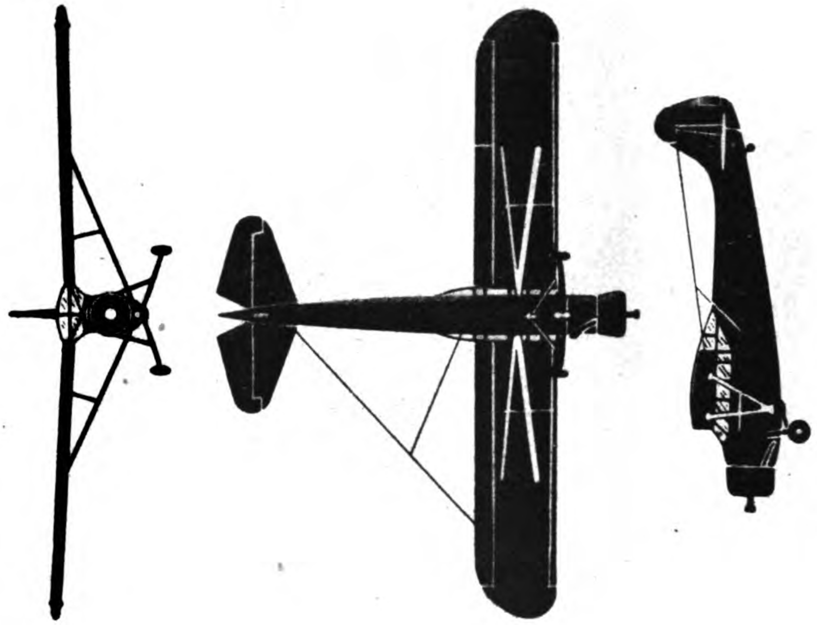


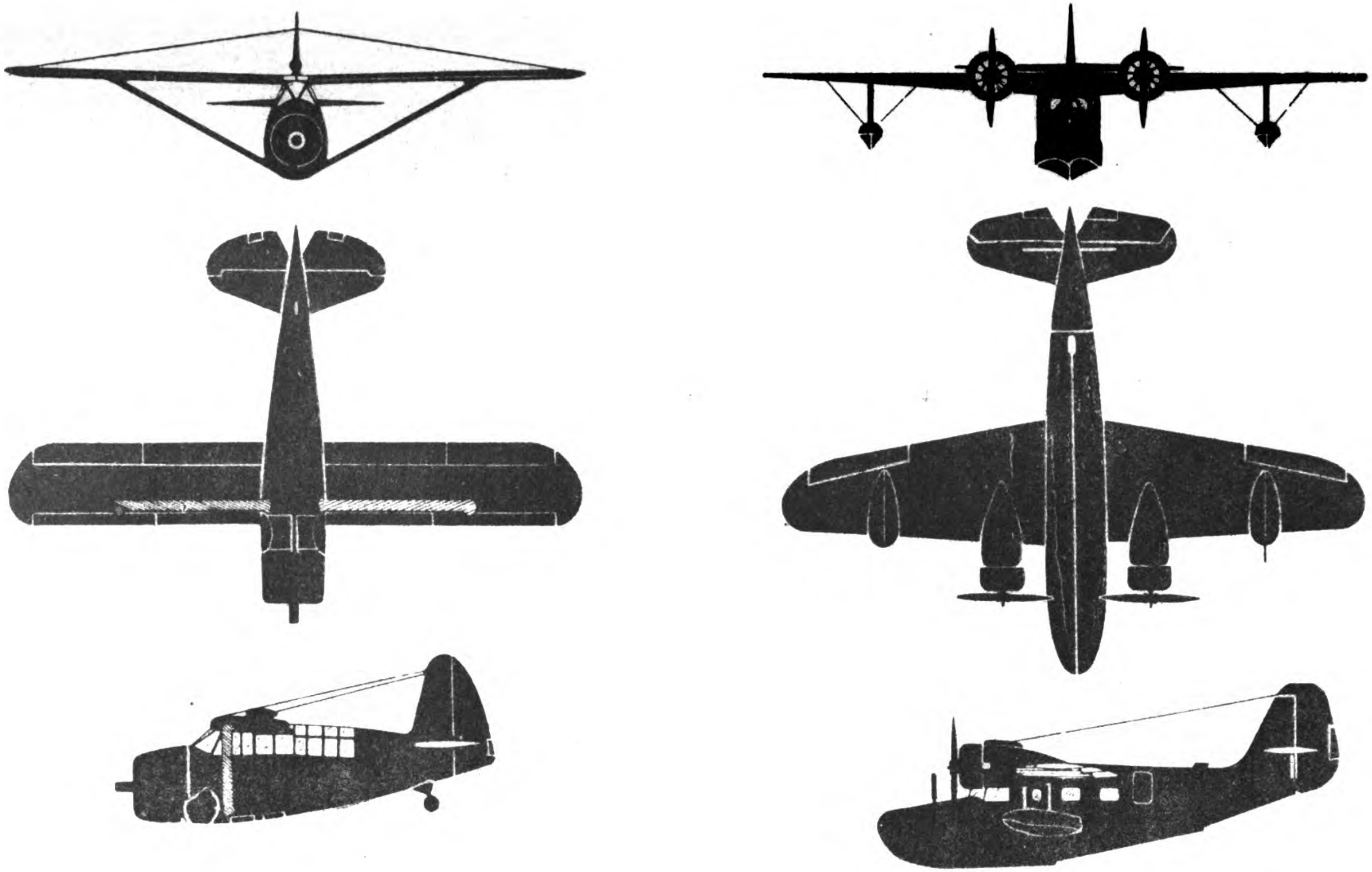
FIGURE 191 ①.—Douglas O-46A—observation airplane.



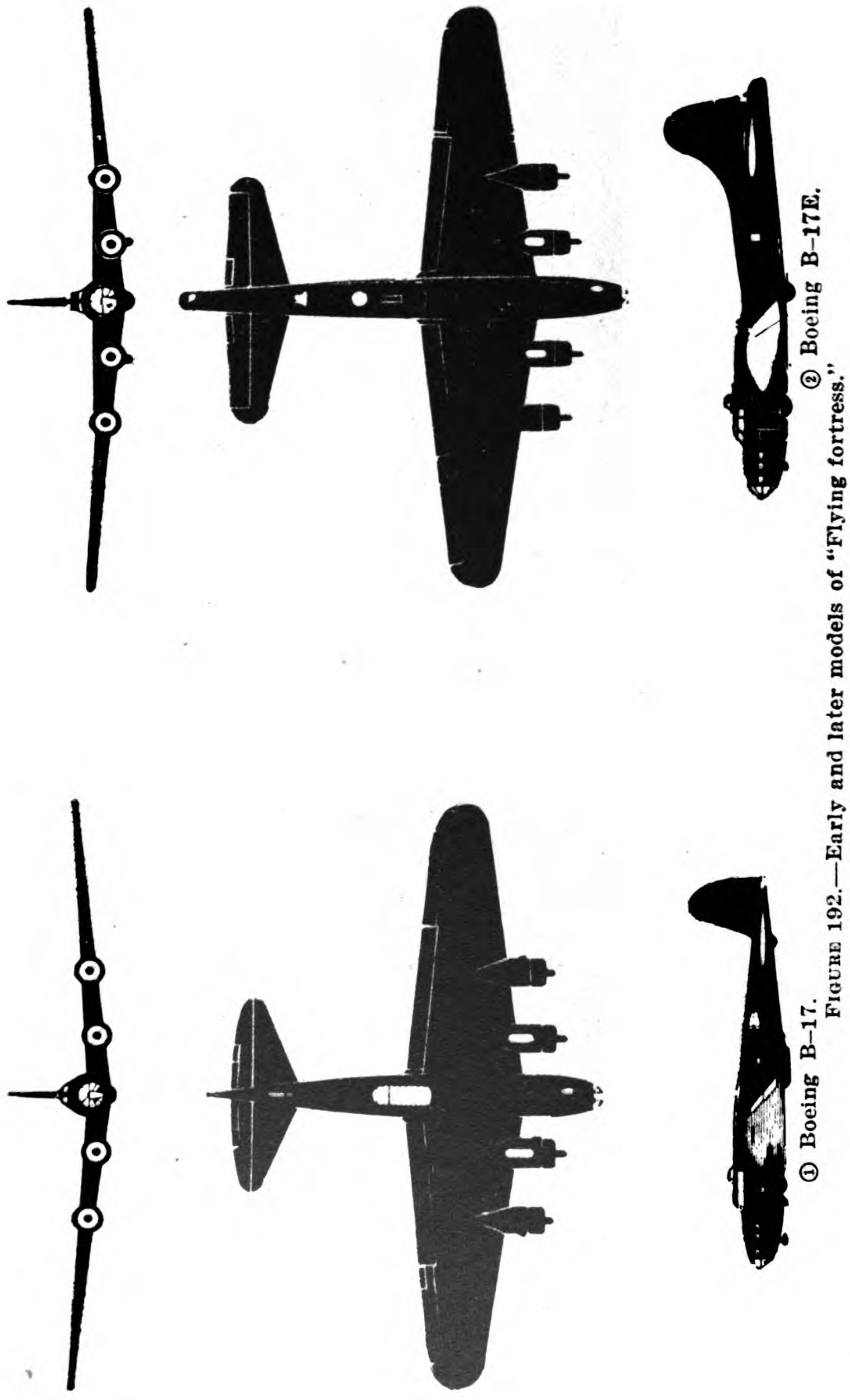
②.—North American O-47A.



③ Stinson O-49.



④ Curtiss O-52. FIGURE 191.—Observation airplanes—Continued. ⑤ Grumman OA-9.



① Boeing B–17.

② Boeing B–17E.

FIGURE 192.—Early and later models of "Flying fortress."

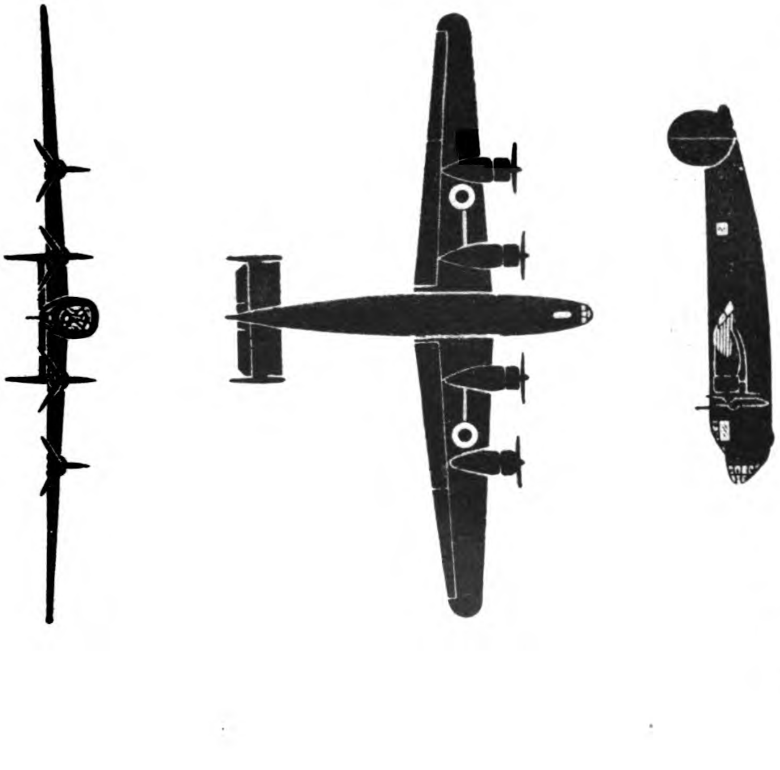


FIGURE 193.—Consolidated B–24 "Liberator", heavy bomber.

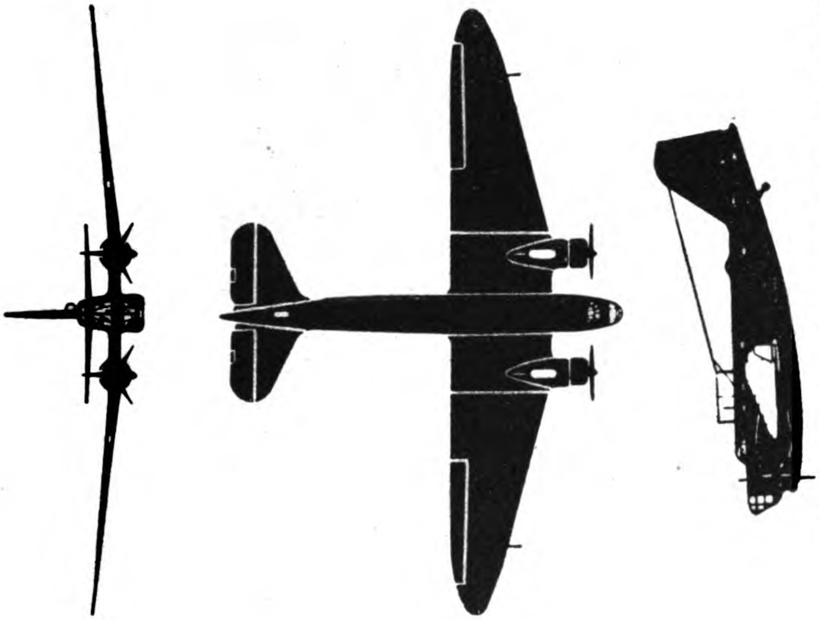
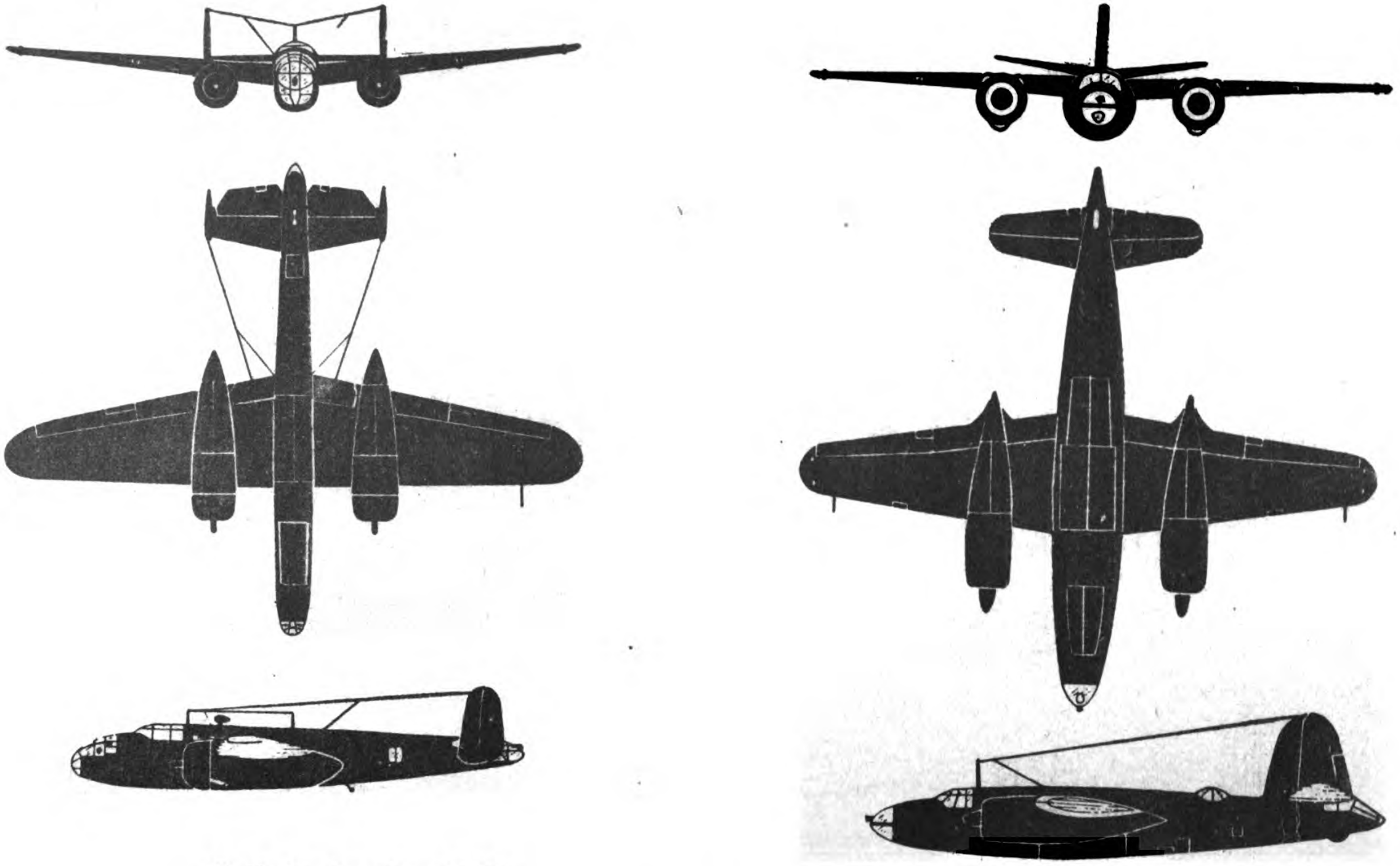


FIGURE 194 ①.—Douglas B–18A medium bomber.



② North American B–25.

③ Martin B–26A.

FIGURE 194.—Medium bombers—Continued.

APPENDIX III

CLASSIFICATION AND USE OF SOILS IN AIRDROME CONSTRUCTION

		Paragraphs
SECTION I.	General	1–3
II.	Soil classification and identification of types	4–9
III.	Use of aerial photographs for soil information	10
IV.	Combined soil types	11–12
V.	Other soil terminology	13–14
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VII.	Compaction	23–27
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IX.	Soil survey	32–34
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XII.	Testing stabilized mixtures and concrete	49–50
XIII.	Subsurface drainage for pavements	51–54

SECTION I

GENERAL

	Paragraph
Importance	1
Foreign soils	2
What constitutes soil	3

1. Importance.—Knowledge of the physical properties of soils is essential in solving problems of design and construction of runways, taxiways, hard standings, access roads, and foundations for hangars and other structures of military airdromes. Due to the urgency of much of this construction usually neither time nor facilities are available for a complete laboratory study of the soils encountered. Accordingly the engineer must rely on his ability to identify soils and judge their properties from visual inspection and simple classification tests performed in the field. He must be able to decide promptly which of the available soils is best suited for the construction of a road or runway; whether drainage is necessary or feasible; whether a soil is sensitive to frost action; and what type of treatment is best adapted for stabilization of a given soil.

2. Foreign soils.—Soils in foreign countries may have to be utilized without adequate time and facilities for study. Information may be obtained from allied troops or from local sources; otherwise the engineer must rely upon his observation, analysis, and judgment. In judging foreign soils it is important to remember that soils developed under the same conditions of climate, topography, and parent material are related and have similar engineering characteristics. This fact makes it possible to translate and apply soils experience from one region to another. Foreign soils should be judged on the basis of their engineering characteristics as disclosed by identification and test procedures explained in this appendix. These procedures are universally applicable. As in the United States many foreign countries have published agricultural soil classification maps and geological maps which may be helpful.

3. What constitutes soil.—"Soil" is a generic term which includes practically every type of earthen material, including artificial fill, soft shales, and partly cemented sandstones. Most soils consist mainly of a heterogeneous accumulation of mineral grains which are not cemented together. Voids between these grains may be filled partly or completely with water. In addition, some soils contain organic material in various forms and amounts. In peaty soils organic substances predominate, consisting largely of coarse, partly decomposed vegetable matter. In some clays, organic material which is present only in very small quantities in colloidal form has an important bearing on physical properties.

SECTION II

SOIL CLASSIFICATION AND IDENTIFICATION OF TYPES

Paragraph
Classification ---- 4
Gravel ---- 5
Sand ---- 6
Silt (rock flour) ---- 7
Clay ---- 8
Organic soil ---- 9

4. Classification.—The entire range of physical characteristics of soils is best illustrated by describing the following five principal types of soils, and the methods for their identification: gravel, sand, silt (rock flour), clay, and organic. Most other types of soils can be described by combining the above names to reflect the principal characteristics of such composite types.

5. Gravel.—*a. General description.*—Bulky mineral grains of natural occurrence ranging from about 0.08 inch to 3 inches in diameter are called gravel. Gravels are classified according to size and uniformity as coarse, medium, fine; well-graded or uniform; and according to surface characteristics, as angular or rounded. Natural deposits of gravel often are referred to as pit-run or bank-run gravel. Such deposits usually contain a considerable percentage of sand, and often of silt and clay. In many instances this improves the grading of the mixture.

b. Identification.—Clean gravel is identified readily by inspection, due to size of individual grains.

c. Engineering characteristics.—Next to sound bedrock, well-graded gravel with suitable filler represents the most stable natural foundation material. Due to low compressibility and high internal friction, and to the fact that it can be compacted properly with minimum effort, it is the most desirable material for foundations and base courses. Desirable qualities of gravel increase with average size, angularity, and gradation, except that larger sizes must be excluded from surface courses.

6. Sand.—*a. General description.*—Sand consists of mineral grains ranging in size from about 0.08 inch to 0.002 inch in diameter. These dimensions cover particles passing a No. 10 sieve and retained on a No. 270 sieve. (Sieve number refers to the number of openings in the sieve per linear inch. See table LIV for actual dimensions.) Sand particles larger than about No. 40 sieve are called coarse sand. Medium sand ranges between approximately No. 40 sieve and No. 100 sieve. Smaller sizes are classified as fine and very fine sands. Further differentiations are based on the gradation of the sand and the angularity of its grains. (This definition of sand size differs from the meaning of the term in concrete, bituminous, and general construction, where the fine aggregate passing a No. 3 or No. 4 sieve is commonly called sand. Likewise, this definition of sand size differs slightly from the U. S. Bureau of Soils designation with respect to classification of agricultural soil constituents.)

b. Identification.—Coarse and medium sands may be readily identified by visual inspection, while very fine sands sometimes are mistakenly identified as silts or even clays. To prevent such mistakes, samples should be subjected to visual and manual inspection in the dry condition. Dried samples exhibit no cohesion; character and size of the grains can be identified to some extent by the degree of grittiness when feeling the material. Quantitative determination of the grain size and gradation requires sieve analysis.

c. Engineering characteristics.—Well-graded, angular sand approaches gravel as a desirable foundation material. The finer and more uniform a sand, the more attention is required to stabilization processes.

7. Silt (rock flour).—*a. General description.*—Silt consists of natural mineral grains which pass a No. 270 sieve, lack plasticity, and possess little or no cohesion when dry. Due to the fact that the name "silt" has been used frequently to designate certain organic alluvial soils, it is often desirable to use the terms "inorganic silt," or "rock flour," to prevent misunderstandings. The term rock flour usually is reserved for inorganic silts of glacial origin which contain no clay and are relatively uniform in gradation. Except for such glacial deposits, clean inorganic silts are very rare. Usually an inorganic silt contains sufficient sand or clay, or both, to require classifications as sandy silt, clayey silt, silt-clay, etc., as described in table XXXII.

b. Identification.—Two simple tests, readily performed in the field, permit positive identification. First is the "shaking test." Prepare a pat of wet soil, adding water if necessary. Then shake horizontally in the palm of the hand, which, for typical inorganic silt, will cause water to come to the surface of the sample. In this condition, the sample appears glossy and rather soft. Squeezing the sample between the fingers causes the water to disappear from the surface, which seems to dry up. Then the sample stiffens and finally cracks or crumbles. Second is the "breaking test." Allow the sample to dry; test its cohesion and feel by breaking up with the fingers. Typical inorganic silt shows little or no cohesion when dry, and possesses a smooth feel in contrast to the grittiness of fine sand, for which it is sometimes mistaken. More frequently inorganic silts are misclassified as clays, due to their fineness and color.

c. Engineering characteristics.—All types of inorganic silts are treacherous soils. Due to their inherent instability, slight disturbances may cause them to become soft, or to change into a "quick" condition. They are much more compressible than sands, and when ground water or seepage is present they are subject to intensive ice segregation when exposed to frost action. This is very destructive to pavements. They are extremely difficult to compact; subdrainage is not sufficiently effective to increase their stability.

8. Clay.—*a. General description.*—Clay consists of very fine mineral particles ranging from silt well down into truly colloidal sizes. Colloidal particles are so small that they will remain suspended in water indefinitely. All clays display, between certain moisture contents, the physical property known as plasticity, which is utilized for classification purposes. Depending upon the degree of plasticity and the contents of coarser grain sizes, one can distinguish between sandy clays, silt-clays, clays having low plasticity or lean clays, highly plastic clays or fat clays, etc. Many clays, brittle in their undisturbed state, become very soft and plastic upon being worked. As a result of alternate wetting and drying, vegetation and frost action, or general weathering, clays may undergo radical changes in color (oxidation) and physical properties.

b. Identification.—(1) Much confusion results because the term "clay" is generally used both as designation of fine-grained soils having plasticity, as well as for classification of grain sizes smaller than 0.005 mm (U. S. Bureau of Soils Classification) or 0.002 mm (International Classification). Although highly plastic clay may contain not more than 30 percent of grains smaller than 0.005 mm in size, it would be misleading to term such a soil a clayey silt, just because the major portion of grains falls into the silt fraction. Conversely, a very fine rock flour may contain more than 50 percent of grains smaller than 0.005 mm in size, but because of physical properties it should classified as typical inorganic silt and not as silty clay. From a practical point of view, it is important that the names silt and clay be reserved for designation of soils having corresponding physical characteristics. The terms "silt sizes" and "clay sizes" should be used when referring to fine fractions in grain-size classification.

(2) The characteristics of clay in its plastic range and its hardness in the dry state afford positive means for identification and classification. By remolding a piece of clay and adding water when the stiffness requires, it can be transformed into a plastic mass which can be kneaded like dough. Hardness of a dried sample can be measured by intensity of finger pressure required to break up the sample. While it is simple to identify a clay positively by such means, some experience is required to ascertain degree of plasticity from feel of the material in the plastic range and from its strength in the dried state.

(3) The consistency of a clay in its undisturbed state is independent of the characteristics discussed above. It may range from hard through stiff, medium, soft, and very soft. Hard clay requires the use of a pick for excavating. It cannot be remolded by the use of the fingers. Medium clay can be excavated with a spade. This type can be remolded by applying ordinary pressure with the fingers. Soft clay can be readily excavated with a shovel and easily remolded by hand.

c. Engineering characteristics.—Low resistance to deformation, high compressibility, and imperviousness are inherent properties of clays. Appraisal of engineering characteristics of clays is complicated by the fact that even the same type of clay may vary widely in resistance to deformation, depending on water content. To permit its use as a pavement foundation, highly plastic clay, when soft, requires removal of a larger percentage of pore water than is feasible with ordinary construction methods. On the other hand, when the same clay is found in a relatively dry and hard condition, it may be possible to compact it, if necessary, with addition of an appropriate amount of water to permit its use as a satisfactory base for pavement construction. In all cases, special attention must be paid to possible magnitude of volume change due to alternate shrinkage and expansion. While for coarser soils visual and manual inspection often suffices for decisions on their control, clays require, in general, some quantitative tests on natural water-content, plasticity, shrinkage, compaction, and swelling characteristics. Expansion or swell characteristic is indicated by the percent of swell of a sample during saturation in the "bearing-ratio" test procedure (par. 46 (app. III)). A swell of more than 3 to 5 percent in this test is unfavorable.

9. Organic soil.—*a. General description.*—Organic soils are chiefly of two types: peaty soils, consisting largely of partially decomposed vegetation; and fine-grained plastic and nonplastic mineral sediments containing varying amounts of finely divided vegetable matter. The latter may be classified, depending on grain size and plasticity, as organic sandy silt, organic silt or organic silt-clay, and organic clay. Even a small percentage of organic matter may increase materially the compressibility of fine-grained soils, and may have other important effects upon its physical characteristics. Therefore, the word "organic" should always be added to the classification of the soil, unless the name already implies organic material.

b. Identification.—Since organic matter in peaty soils is coarse and fibrous, identification of such soils offers no difficulty. In organic silts and clays, however, organic matter is usually so finely divided that it cannot be detected by visual inspection, and some of it is even colloidal in character. In many cases, the organic odor is strong enough to be easily detected. When in doubt, one can intensify the odor by quickly heating a small sample until the surface appears dry. When such soils possess plasticity, they feel somewhat spongy in the plastic range as compared to inorganic clays. Experience, however, is required to utilize this fact for identification purposes. Liquid and plastic limit (pars. 42, 43 (app. III)) tests performed before and after drying are also useful for identifying plastic organic soils. Drying produces material decrease in values of these limits. Finally, the plot of liquid limit vs. plasticity index offers empirical relationships which are useful in determining the presence of organic matter in plastic soils.

c. Engineering characteristics.—All peaty and plastic organic soils are unsatisfactory subgrades due to their high compressibility, and low shear strength. In general, they require either removal or a thick foundation course of a higher type soil. On organic soils of relatively low compressibility, properly designed concrete pavements may be used with only a subgrade blanket course of sand or gravel, if higher type soils are not available for construction of a foundation course. Nonplastic organic soils without coarse organic constituents, such as topsoils classified as organic sandy silt, possess essentially the same characteristics as corresponding inorganic soils.

SECTION III

USE OF AERIAL PHOTOGRAPHS FOR SOIL INFORMATION

Paragraph
Aerial photographs ---------- 10

10. Aerial photographs.—*a.* From study of aerial photographs of an area whose geology, soil, and vegetation characteristics are known it is often possible to learn something of soils from aerial photographs of unknown areas in the same region.

b. Vegetation or tree growth in a region is influenced by soil conditions. Knowledge of the relationship between plant life and soil in one area may provide clues to soil conditions in an adjacent area through identification of vegetation in aerial photographs of that area provided elevation and rainfall of the two areas are similar. Deposits of granular material beneath the surface may be located thus from ground surface configuration and vegetation similarities noted in aerial photographs.

c. Different styles of drainage pattern in a region carry significance with respect to topography, texture of soil, and its drainage characteristics. A small stream that flows in wide meanders across an area indicates that the general drainage area is flat to gently undulating, that the soil has a fairly heavy texture, and that surface run-off dominates the drainage. The absence of meandering streams in a flat terrain in an adjacent area generally means that rainfall is largely absorbed by the soil with little or no surface run-off, hence the soil is well drained internally and favorable for runway subgrade.

d. Glaciated regions have many characteristics identifiable in aerial photographs that may be helpful in disclosing soil information concerning an area in that type of region. The soil on the downstream side of a glacial lake is generally granular, hence good subgrade and a promising area for sand and gravel pits. Deposits of granular material in moraines left by melting or receding glaciers often have characteristic shapes. Recognition of these in aerial photographs gives valuable clues as to the soil to be found.

e. Hills of half-moon or dune shape imply soil of wind-blown origin that implies a very definite limit on maximum particle size as well as characteristic gradation. The soil may be coarse and sandy or fine loess. Vegetation and local erosion may differentiate them. Erosion slopes in sandy soil are similar to the angle of repose of sand piles, whereas eroded loess stands in very steep banks.

SECTION IV

COMBINED SOIL TYPES

Paragraph
Sand-gravel mixtures ---------- 11
Sand-silt-clay mixtures ---------- 12

11. Sand-gravel mixtures.—*a.* Well-graded mixtures of gravel and sand deform less under load than uniform sand. Generally these are good materials, but there may be exceptions. A small content of silt or plastic clay, or both, usually has little effect on compressibility characteristics, but may be seriously objectionable from the standpoint of frost action. Presence of even a small percentage of plastic clay may render such soils difficult or impossible to compact.

b. Identification of small quantities of silty or clayey material can be made by rubbing moist soil against the palm of the hand and then wiping off all grains of visible size. Examination of any material adhering to the hand permits, with little experience, classification of the finest fraction.

c. Depending on the predominant soil property, names such as clean sandy gravel, dirty gravel, clayey gravel, gravelly sand, etc., are used for classification purposes.

12. Sand-silt-clay mixtures.—*a.* This group comprises the largest variety of soils, ranging from stable, well-graded sands containing only small quantities of silt or clay, or both, to silty clays with high compressibility and expansion characteristics. Some of these mixtures have very desirable engineering characteristics while others are unsatisfactory. From the standpoint of compaction, the most difficult soils in this group are silts containing only small quantities of sand or clay, or both. On the other hand, many types of silty clays lend themselves well to compaction.

b. Regarding drainage characteristics, soils in this group range from relatively well-draining silty sands to practically impervious silty clays. When judging feasibility of draining a subgrade, special attention should be paid to stratification. A subgrade consisting of alternating thin layers of sandy and silty soils could be drained in its undisturbed state, but would appear as a relatively impervious soil if tests are made of disturbed samples in which all layers are mixed.

c. Examples of names used for classifying soils in this group are silty sand, clayey sand, silty sand with trace of clay, very sandy silt, sandy silt with some clay, clayey silt, sandy clay, silty clay, sandy-silty clay, etc. These names reflect physical properties of combined soils as described for principal soil types. They definitely do not coincide with classifications based on the quantitative ratios of the various fractions as derived from grain-size analyses.

Section V

OTHER SOIL TERMINOLOGY

Paragraph
Cohesion 13
Miscellaneous 14

13. Cohesion.—For many purposes, as when dealing with compaction characteristics of soils, it is useful to group soils in two main classifications on the basis of cohesion in the dried state (dry strength):

a. Noncohesive (*cohesionless*) *soils* are all noncemented sands, gravels, and sand-gravel mixtures, containing little or no plastic clay. They will develop practically no cohesion when dry. They are also called granular or nonplastic materials.

b. Cohesive soils are all *plastic soils*, and such sandy or gravelly soils containing enough plastic clay as a binder to create upon drying a coherent mass which cannot readily be broken up into individual grains.

14. Miscellaneous.—There are numerous soil names in existence which describe either the geologic origin of the soil or its outstanding physical properties, or a soil type of regional distribution. Frequently adjectives are used describing the composition, some characteristic material contained in the soil, or some state of induration (hardening) or structure. The following is a list of some of the more important terms with their definitions:

a. Adobe.—A term applied to calcareous sandy silts and sandy-silty clays found in the semiarid regions of the southwestern United States.

b. Calcareous.—An adjective indicating an appreciable content of calcium carbonate (limestone).

c. Caliche.—Essentially a soft limestone containing varying percentages of silt and clay, occurring chiefly in the southwestern United States.

d. Carbonaceous.—An adjective marking the presence of sufficient carbonized organic matter to give the soil a dark color.

e. Diatomaceous.—An adjective denoting an appreciable content of silicious (silica) shells of minute organisms called "diatoms."

f. Ferruginous.—An adjective indicating the presence of sufficient ferrous (iron) compounds to impart to the soil a brownish or reddish color.

g. Gumbo.—A very sticky, highly plastic clay.

h. Gypsiferous.—An adjective denoting the presence of small particles of gypsum.

i. Hardpan.—A loosely used term describing soils which have become compact or hard due to consolidation under very large overburden pressure, or due to cementation or induration (hardening), or some combination of these influences.

j. Loam.—A term loosely used, applying most frequently to sandy-silty top soils containing a trace of clay.

k. Loess.—A silty soil of eolian (wind-blown) origin, characterized by a loose, porous structure which permits it to stand in cuts with vertical walls. The physical characteristics vary widely, depending in part on the presence of calcareous material.

l. Marl.—A term referring to a wide range of richly calcareous clays, silts, and fine-grained sands. It occurs extensively in the Gulf Coast area, where it is locally called "limerock."

m. Micaceous.—An adjective denoting the presence of sufficient visible mica flakes to give the soil a distinctive appearance.

n. Till.—The unsorted deposit of glaciers containing mixtures of widely different sizes ranging from boulders to clay. Some types of till are known as boulder clay, while others are referred to as hardpan.

SECTION VI

CLASSIFICATION OF SOILS

	Paragraph
Detailed classification	15
Equivalents in Public Roads Administration classification	16
Field identification	17
Classification by sieve analysis	18
Classification by liquid and plastic limits	19
Natural condition of subgrade	20
General characteristics of soil groups	21
Characteristics of average soils	22

15. Detailed classification.—*a.* Based on a comprehensive study of requirements of soil classification for airdrome runway design, the following classification by Casagrande is presented for use in connection with subgrade studies and design of base courses. The classification is illustrated in table XXXII.

(1) The *coarse-grained soils* are subdivided into—

(*a*) Gravel and gravelly soils, for which the symbol G is used.

(*b*) Sands and sandy soils, for which the symbol S is used.

(2) The *fine-grained soils* are subdivided into—

(*a*) Fine-grained soils having low to medium compressibility, for which the symbol L is used.

(*b*) Fine-grained soils having high compressibility, for which the symbol H is used.

(*c*) The group of soils comprising all highly organic fibrous soils, such as peat and swamp soils of various types, for which the symbol Pt is used.

(3) *Gravels and sands* are each divided into four groups:

(*a*) Well-graded, fairly clean material, represented by symbol W.

(*b*) Well-graded material with excellent clay binder, represented by symbol C.

(*c*) Poorly graded, fairly clean material, represented by symbol P.

(*d*) Material containing an excess of fines, represented by symbol F.

(4) Each of the two divisions of fine-grained soils is divided into three groups:

TABLE XXXII.—*Soil classification*

Major divisions	Soil groups and typical names	Group symbols
Coarse-grained soils: Gravel and gravelly soils	Well-graded gravel and gravel-sand mixtures; little or no fines.	GW
	Well-graded gravel-sand-clay mixtures; excellent binder.	GC
	Poorly graded gravel and gravel-sand mixtures; little or no fines.	GP
	Gravel with excess of fines, very silty gravel; clayey gravel, poorly graded gravel-sand-clay mixtures.	GF
Sands and sandy soils	Well-graded sands; little or no fines.	SW
	Well-graded sand-clay mixtures; excellent binder.	SC
	Poorly graded sands; little or no fines.	SP
	Sand with excess of fines; very silty sands, clayey sands, poorly graded sand-clay mixtures.	SF
Fine-grained soils (containing little or no coarse-grained material): Fine-grained soils having low to medium compressibility.	Silts (inorganic) and very fine sands; MO[1], rock flour, silty or clayey fine sands.	ML
	Clays (inorganic) of low to medium plasticity; sandy clays, silty clays, lean clays.	CL
	Organic silts and organic silt-clays of low plasticity.	OL
Fine-grained soils having high compressibility.	Micaceous or diatomaceous fine sandy and silty soils; elastic silts.	MH
	Clays (inorganic) of high plasticity; fat clays.	CH
	Organic clays of medium to high plasticity.	OH
Fibrous organic soils with very high compressibility.	Peat and other highly organic swamp soils, such as muck.	Pt

[1] Swedish term for soil in this class.

table for airdromes (*Casagrande*)

Field identification and cohesion in dry state	Classification tests	Observations and tests relating to natural condition of subgrade
Readily identified, no cohesion.	Sieve analysis.	Solids per cubic foot of undisturbed soil; Degree of compaction; stratification. Bearing ratio tests (California) on undisturbed soil or large size load tests. Drainage characteristics for soils containing considerable fines.
Examination wet and dry; medium to high cohesion.	Sieve analysis, liquid and plastic limits on binder.	
Readily identified; no cohesion.	Sieve analysis.	
Examination wet and dry; slight to high cohesion.	Sieve analysis, liquid and plastic limits on binder if applicable.	
Readily identified; no cohesion.	Sieve analysis.	
Examination wet and dry; medium to high cohesion.	Sieve analysis, liquid and plastic limits on binder.	
Readily identified; no cohesion.	Sieve analysis.	
Examination wet and dry; slight to high cohesion.	Sieve analysis, liquid and plastic limits on binder if applicable.	
Examination wet and dry; shaking test in wet state; very slight to medium cohesion.	Sieve analysis, shrinkage limit, liquid and plastic limits if applicable.	Natural water content or void ratio. Consistency undisturbed and remolded. Bearing ratio tests (California) or large size load tests on undisturbed soil. Drainage characteristics for nonplastic and stratified soils.
Character in plastic range and dry state; medium to high cohesion.	Liquid, plastic, and shrinkage limits.	
Character in plastic range, odor and color wet and dry; slight to medium cohesion.	Liquid, plastic, and shrinkage limits from natural condition, and after oven drying.	
Examination wet and dry; shaking test in wet state; slight cohesion.	Sieve analysis, shrinkage limit, liquid and plastic limits if applicable.	
Character in plastic range and dry state; high cohesion.	Liquid, plastic, and shrinkage limits.	
Character in plastic range, odor and color wet and dry; high cohesion.	Liquid, plastic, and shrinkage limits from natural condition, and after oven drying.	
Readily identified	Natural water content and shrinkage limit undisturbed.	

TABLE XXXII.—*Soil classification*

Major divisions	Value as foundation material when not subject to frost action	Value as wearing surface with satisfactory dust palliative	Potential frost action
Coarse-grained soils: Gravel and gravelly soils.	Excellent	Poor	None to very slight.
	Excellent	Excellent	Medium
	Excellent	Poor	None to very slight.
	Good to excellent.	Fair to good	Slight to medium
Sands and sandy soils	Excellent	Poor	None to very slight.
	Excellent to good.	Excellent	Medium
	Good to fair	Poor	None to very slight.
	Fair	Fair to good	Slight to high
Fine-grained soils (containing little or no coarse-grained material): Fine-grained soils having low to medium compressibility.	Fair to poor	Poor	Medium to very high.
	Fair to poor	Poor	Medium to high
	Poor	Very poor	Medium to high
Fine-grained soils having high compressibility.	Poor	Very poor	Medium to very high.
	Poor to very poor.	Very poor	Medium
	Very poor	Useless	Medium
Fibrous organic soils with very high compressibility.	Useless	Useless	Slight

table for airdromes (*Casagrande*)--Continued

Shrinkage, expansion, elasticity	Drainage characteristics	Compaction characteristics and equipment	Dry weight per cubic foot at optimum compaction pound per cubic foot	Bearing ratio (California) for compacted and soaked specimen	Equivalent group in Public Roads Administration classification
Practically none.	Excellent	Excellent, tractor.	>125	50 over 100	A-3
Very slight	Practically impervious.	Excellent, sheepsfoot roller.	>130	40-90	A-1
Practically none.	Excellent	Good, tractor	115-130	25-50	A-3
Practically none to slight.	Fair to practically impervious.	Good, close control essential, tractor, sheepsfoot roller.	120-130	20-60	A-2
Practically none.	Excellent	Excellent; tractor.	>120	25-50	A-3
Very slight	Practically impervious.	Excellent; sheepsfoot roller.	>125	20-50	A-1
Practically none.	Excellent	Good; tractor	110-125	10-25	A-3
Practically none to slight.	Fair to practically impervious.	Good, close control essential; tractor or sheepsfoot roller.[2]	110-125	8-30	A-2
Slight to medium.	Medium to poor	Good to poor, close control essential, usually sheepsfoot roller.[2]	100-120	6-15	A-4
Medium	Practically impervious.	Fair to good; sheepsfoot roller.	100-120	4-15	A-6
Medium to high.	Poor	Fair to poor; sheepsfoot roller.	90-110	3-8	A-6
High	Medium to poor.	Very poor	<100	3-8	A-5
High	Practically impervious.	Fair to poor; sheepsfoot roller.	80-110	<6	A-7
High	Practically impervious.	Very poor	<100	<4	A-7
Very high	Fair to poor	Compaction not practical			A-8

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[2] For best results, compact in thin layers with rubber tired rollers.

(*a*) Silty and very fine sandy soils, symbol M (an abbreviation of the Swedish term "MO" as used in the international grain size classification).

(*b*) Inorganic clays, symbol C.

(*c*) Organic fine-grained soils, symbol O.

b. In table XXXII typical names are assembled for each soil group and the corresponding group symbol is shown in the adjacent column. Study of the names contained in this classification will show that it actually represents no new soil classification. The names are those which every experienced soil engineer uses when describing a soil on the basis of visual and manual examination. Group symbols are definitely not intended to supplement a detailed description by name; their use should be limited.

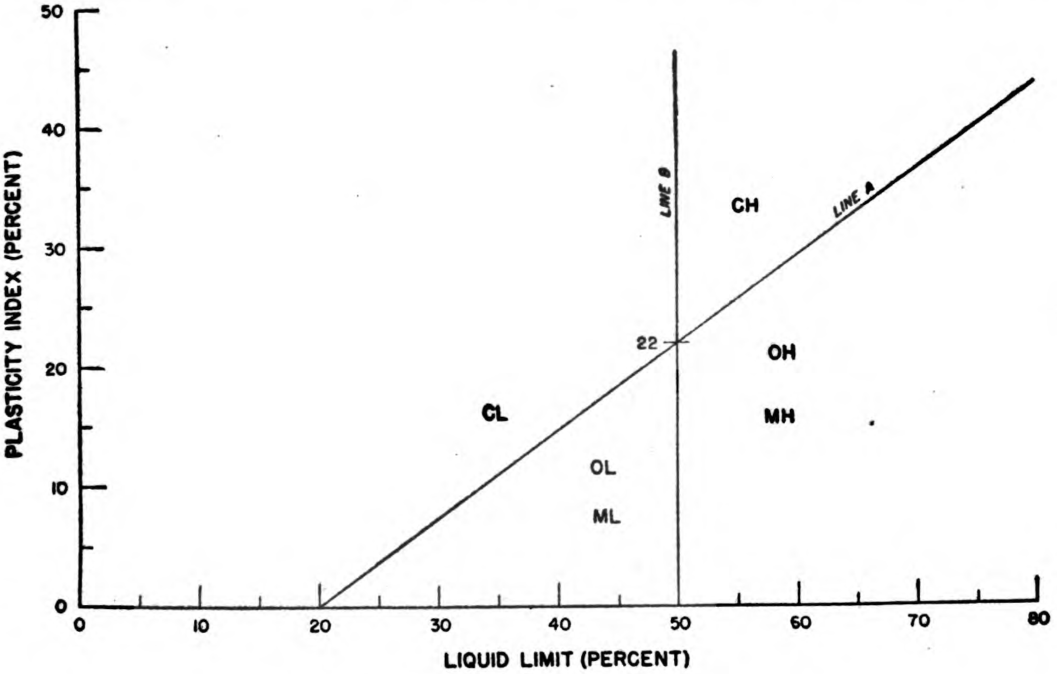
c. A good method of familiarizing oneself with this new classification is by noting the order in which letters in group symbols repeat themselves, and by keeping in mind the meaning of these letters. Once order of the grouping is understood, one can readily reconstruct the entire classification without having to memorize details.

16. Equivalents in public roads administration classification.—For engineers who are familiar with the Public Roads Administration classification, equivalent numbers of that classification are shown in the last column of table XXXII. It should be noted that A–1 group is represented by two groups, GC and SC soils. A–2 group is subdivided into the GF and SF groups. A–3 group is subdivided into four groups: GW, GP, SW, and SP soils. A–4 and A–5 groups find their equivalents in the ML and MH groups. A–6 soils are represented by two groups, the CL and OL materials. A–7 group is subdivided into the CH and OH groups. A–8 group is equivalent to the Pt group in the new classification.

17. Field identification.—*a.* Most coarse-grained soils are easy to identify. When they contain fines, it is advisable to examine the soil both wet and dry. The dry cohesion is always a useful aid in determining whether or not the soil contains clay. Fine-grained soils should always be examined both in the wet and the dry state.

b. For nonplastic and slightly plastic soils the shaking test (par. 7*b* (app. III)) is a helpful aid in identifying soils belonging in the ML and MH groups. Toughness and feel of plastic soils, when somewhat above the plastic limit, assist in estimating their plasticity and sometimes other characteristics also, such as organic content.

18. Classification by sieve analysis.—For all coarse-grained soils and for soils in the ML and MH groups of fine-grained soils, grain-size distribution is the most important quantitative test. Unfortunately, it is not possible to determine proper classification of a soil on the basis of the percentages of sand, silt, and clay sizes. A proper classification of a soil on the basis of the grain-size analysis requires study of the entire grain-size curve. It is probable that one could eventually devise charts showing typical bands which could be used to guide in classification of these soil groups. The coefficient of uniformity, defined as the 60 percent size divided by the 10 percent size, is an index for approximate classification of the gradation of soils in these groups. (See fig. 198.) (Uniformity coefficient is 7.0/0.23=30.4.) Uniformly graded materials have coefficients of uniformity less than 5, and well-graded materials larger than 20. Between these two limits, soil may have properties of a well-graded or of a uniform material, depending on shape of the grain-size curve.



NOTE: PLASTICITY INDEX=LIQUID LIMIT-PLASTIC LIMIT

FIGURE 195.—Soil classification by LL and PI tests.

19. Classification by liquid and plastic limits.—*a.* For all plastic soils, determination of grain-size distribution is of limited usefulness. For such soils, the most important classification tests are liquid and plastic limit tests. (See pars. 42 and 43 (app. III).) These tests are best interpreted by plotting the liquid limit against the plasticity index (see fig. 195). Plasticity index is defined as difference between the liquid and plastic limits. Typical inorganic clay will generally lie above the inclined line *A*. A liquid limit of 50, line

B, is assumed as the dividing line between clays of relatively low compressibility (CL), and clays having high compressibility (CH). Silty and fine sandy soils having some plasticity (ML) and organic silts (OL) generally will lie below line *A* and to the left of line *B*. Organic clays (OH) and micaceous or diatomaceous silty soils (MH) also will plot below line *A*, but to the right of line *B*.

b. The limits of inorganic silty soils (ML, MH) and organic silty and clay soils (OL, OH), when plotted on figure 195, overlap to such an extent that no line of demarcation can be drawn. However, visual and manual inspection is generally sufficient to distinguish between organic and inorganic soils. Also, limits of an organic soil as determined from an oven-dry sample are much smaller than limits of the same soil as determined from a sample in its natural state of moisture; whereas oven drying of an inorganic soil will result in only minor changes in limit values.

20. Natural condition of subgrade.—Field identification and classification tests alone are not sufficient to identify properties of a subgrade in its undisturbed condition. In the column Observations and Tests Relating to Natural Condition of Subgrade, table XXXII, observations and tests are designated for determining pertinent properties of a soil in its undisturbed state.

21. General characteristics of soil groups.—In the remaining columns in table XXXII are tabulated characteristics which are of importance in relation to behavior of soils as subgrade or base course materials. In the next to last column is shown range of the bearing ratio (California) for each soil group. These ranges are also presented in figure 67, which illustrates application of the bearing ratio to design of flexible pavements. Use of the design curves on figure 67 is explained in detail in paragraph 63. Also shown in figure 67 are estimated values of the modulus of soil reaction for various soil groups. These values are for a mass of soil in the saturated state acting as a subgrade to a pavement and were selected after a study of existing test data.

22. Characteristics of average soils.—The results of tests on several thousand samples of soil used in compacted embankment construction indicate a close relationship between maximum weight per cubic foot for any given soil and the liquid limit, plastic limit, plasticity index, and optimum moisture content. Figure 196 shows these relationships for 1,383 individual tests. The curves may be considered as representing average relationships among test results on typical soils. They may be used to aid in soil classification and to hasten field control testing. For example, the plastic limit of a soil, which is easily and quickly determined, is found to be 24 percent. The chart is entered from the left on a horizontal line representing 24 percent to an intersection with the plastic limit curve. A vertical line is drawn

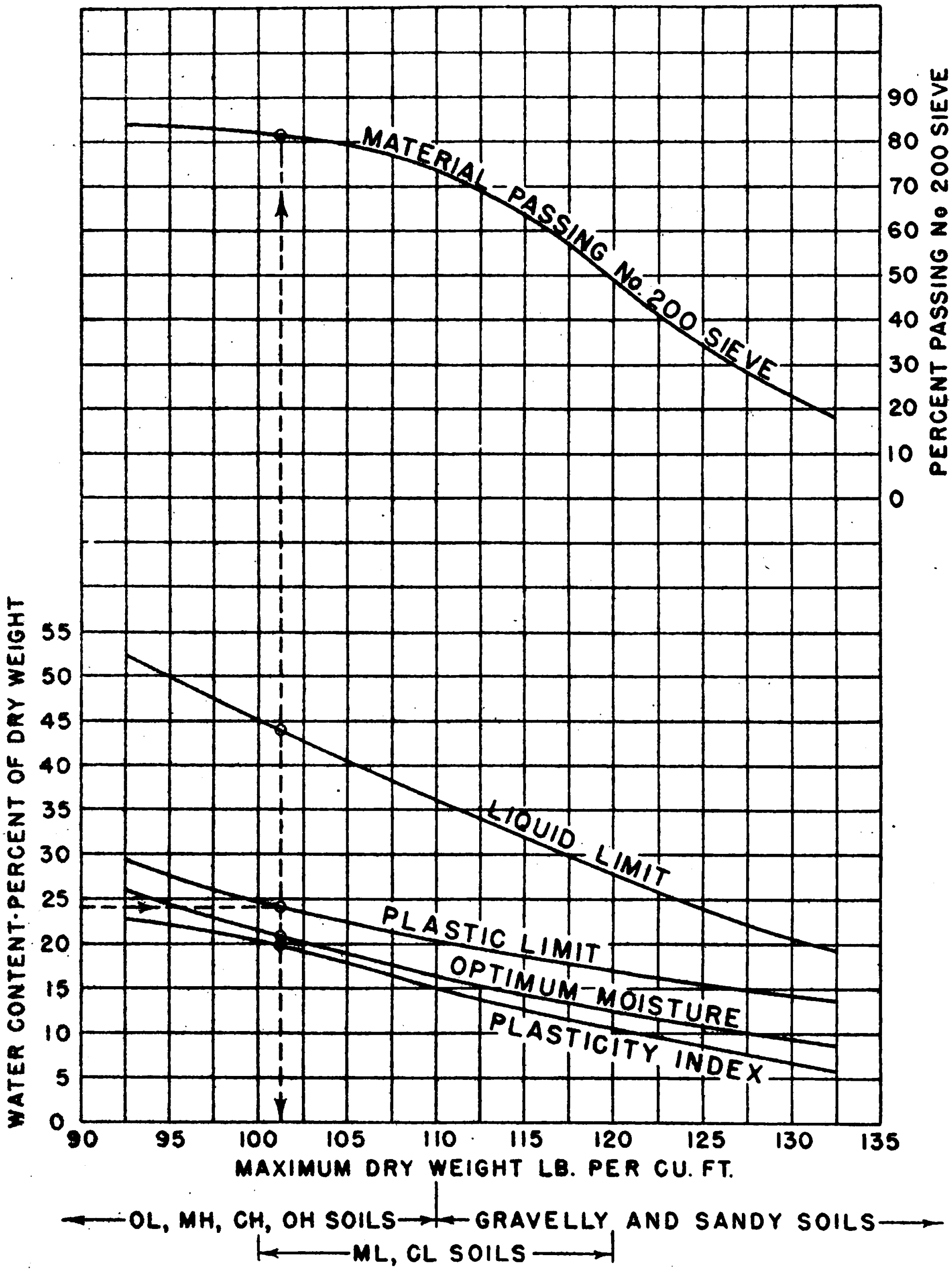


FIGURE 196.—Average soil test values.

through this intersection to cross all other curves in the chart. Other values are then read as follows: material passing No. 200 sieve, 82 percent; liquid limit, 44 percent; optimum moisture, 21 percent; plasticity index, 20 percent; maximum dry weight, 101 pounds per cubic foot. These are average values, not exact for the particular soil in question, but they may be used for preliminary purposes until confirmed by actual test. Similarly, if any other test value is known for a particular soil, preliminary values of the others may be read from the chart.

SECTION VII

COMPACTION

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General 23
Compaction of noncohesive soils 24
Compaction of cohesive soils 25
Soils difficult to compact 26
Requirements for compaction control 27

23. General.—Compaction is the process by which soil grains are rearranged to decrease void space and bring them into closer contact with one another, thereby increasing density and resistance to deformation of the soil mass. Laboratory compaction for preliminary investigation, as well as for control purposes, is obtained by means of compaction tests (par. 45 (app. III)) which simulate the effect of field compaction methods.

24. Compaction of noncohesive soils.—Compaction of granular or noncohesive soils can be accomplished only by a combination of tamping and vibrating. The kneading action of sheepsfoot rollers is definitely detrimental when applied to compaction of such soils. Clean gravels are readily compacted to the dense state, since the individual grains are sufficiently large to be arranged quickly in stable form. When compacting sands, special attention must be given to the detrimental effect of a slight moisture content. This may cause the grains to be held together by capillary forces sufficient, in spite of their very small magnitude, to keep the grains from moving to a denser packing, relative to one another, when subjected to vibrations. Capillary forces can be destroyed either by complete drying or complete immersion. As drying is impractical, saturation of the areas where compaction is in process is a necessary requirement. Sometimes jetting or pounding alone produces sufficient compaction in sands for ordinary purposes.

25. Compaction of cohesive soils.—*a.* Use of cohesive or plastic soils for fill construction requires careful moisture control and compaction with sheepsfoot rollers, in layers of moderate thickness. The soil is compacted at the optimum moisture content determined by standard laboratory compaction tests (see par. 45). Optimum moisture content is not an absolute soil constant, but varies with the weight of the compacting equipment.

b. Cohesive soils which will permit satisfactory compaction are usually those having an optimum moisture content below 20 percent. The simplest indications for determining whether a soil can be used for fill construction is the plastic limit and the natural water content. In general, *those soils having a plastic limit of less than 20 and a natural water content equal to, or less than, the plastic limit, are most suitable for this purpose.* Since the optimum moisture content is slightly below the plastic limit, this limit serves as a satisfactory quick field test for determining when the soil is approximately at the desired moisture content for rolling. Subject to the results of other tests and special requirements, it may be assumed that *the smaller the optimum moisture content, the more satisfactory the soil for construction.*

c. In general, cohesive soils are not found available exactly at the desired moisture content. It is easier to add water to a soil which is too dry than to dry out soil which has too high water content. If the water content is slightly on the high side, excavation, hauling, and rolling operations in dry weather will reduce the moisture to a satisfactory value. The addition of water to dry soils may be accomplished either in the borrow pit or on the fill by the use of sprinkling equipment.

26. Soils difficult to compact.—Clays with a natural water content considerably above the plastic limit are for practical purposes not suited for fill construction, since the large amount of excess water cannot easily be reduced to the low values required for proper compaction. Most silt soils, rock flour, and very fine silty-sands cannot be compacted to form a stable base, and where they occur as subgrade must be blanketed by thick foundation courses. Some natural deposits of sand or gravel, or of both, contain small amounts of highly colloidal fines which render their compaction impossible.

27. Requirements for compaction control.—*a.* Under field conditions, it is not practical to require compaction of the entire working area to the maximum density obtained in laboratory compaction tests. Therefore, limits of acceptability are established which compacted densities must equal or exceed.

b. In "fill" sections, the embankment should be constructed in layers and compacted to 90 percent of the maximum density at optimum moisture, except that directly beneath the pavement the subgrade should be compacted to 95 percent of the maximum density for a depth of not less than 9 inches.

c. In "cut" areas, the subgrade should be scarified and compacted for a minimum depth of 9 inches to 95 percent of the maximum density. This compaction should be accomplished in one layer, without removal, re-laying, or spreading of the subgrade material.

SECTION VIII

TREATMENT OF FROST-ACTION SOILS

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Identification of soils affected by frost action 30
Methods of treatment 31

28. General.—The effects of frost action are heaving of the surface caused by growth of ice layers in the soil and reduction of strength of the soil during periods of thaw due to presence of excess moisture. Damage done to a pavement by frost-heaving is not due to the absolute magnitude of the heaving movement, but rather to differential action caused by nonuniformity in soil composition, stratification within the layers, variation in depth to bedrock, or differences in ground-water level. The reduction in bearing capacity of the subgrade due to frost action necessitates thicker bases and thicker pavements.

29. Mechanics of frost action.—The general mechanics of frost action have been studied by several investigators, and it is known that heaving is caused not by the expansion of natural soil moisture upon freezing, but by the growth of layers or lenses of ice from water furnished by capillary flow. Variables affecting freezing phenomena are grain-size distribution, rate of freezing, and water supply. Soils to which water is readily accessible are affected most by frost action. Clean sands and gravel freeze homogeneously without growth of ice layers; silty sands, silts, and silty-clays cause maximum heaving due to intense ice segregations.

30. Identification of soils affected by frost action.—The only practical method of determining the potential frost-action characteristics of a soil is by reference to the grain-size distribution. Limits have been established for grain size curves defining the boundary between frost-action and nonfrost-action soils of uniform and nonuniform grading. It was found empirically that uniform sandy soils with more than 10 percent by weight finer than 0.02 mm, and well-graded sandy or gravelly soils with more than 3 percent by weight finer than 0.02 mm, are subject to frost action, *if water and freezing conditions are conducive.* Highly plastic cohesive soils do not heave sufficiently to have a detrimental effect because of movement of the surface, but are sufficiently affected to cause reduction in strength during periods of thaw.

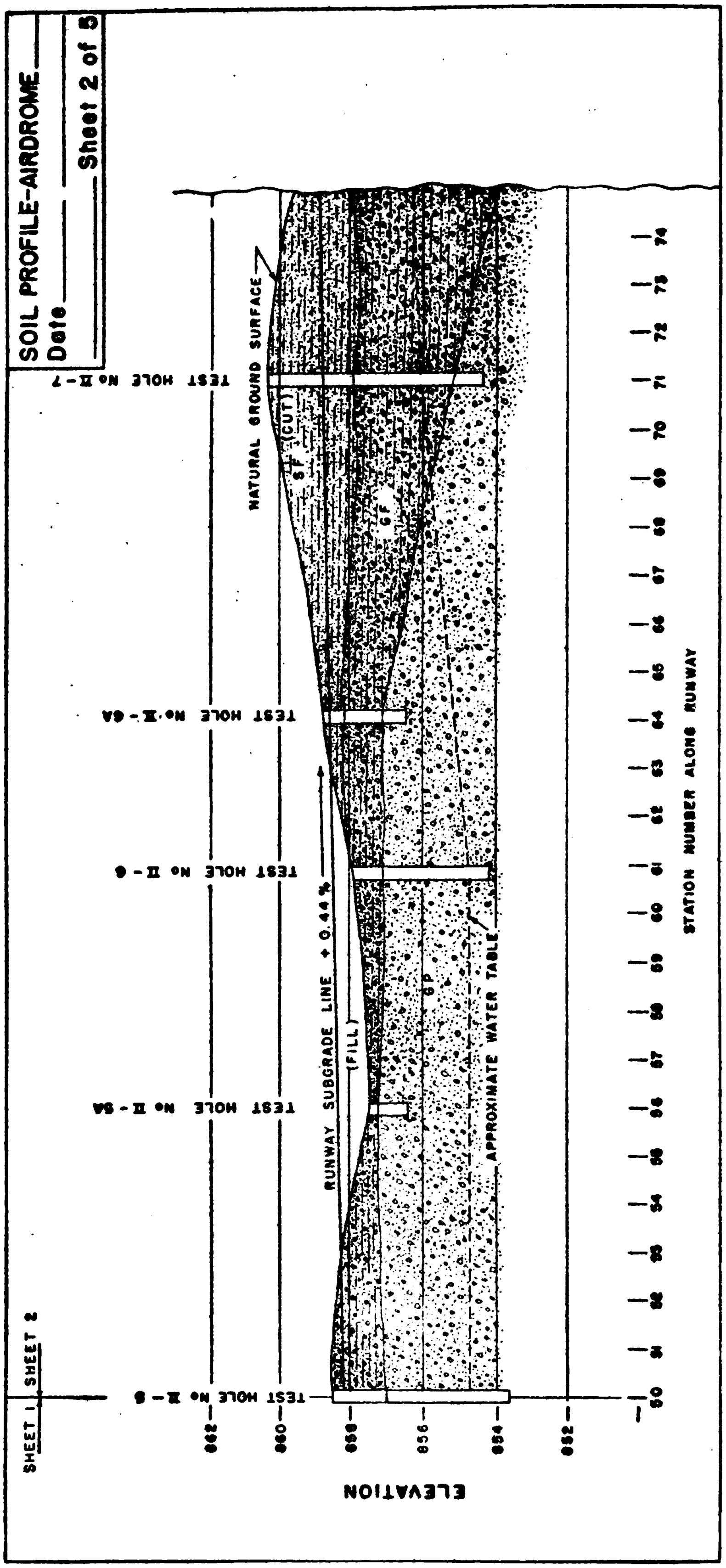
31. Methods of treatment.—Methods for control of frost-heaving are drainage, use of layers of pervious material to intercept the supply of capillary water, and replacement of frost-heaving soil by nonheaving material. The last procedure is applicable only to replacement of silt or clay pockets in an otherwise satisfactory soil. *Drainage is of major importance in preventing frost action*, since presence of a high ground-water table may render an otherwise stable soil undesirable from the standpoint of frost-heaving. For very uniform sand soils and those having a small percentage of the grain size below 0.02 mm in diameter, drains alone are sufficient to prevent frost-heaving, because the height to which capillary moisture can rise is limited to a few feet. This is not true for soils high in silt content, because while drainage will lower the ground-water table, the height of capillary rise is greater than the depths to which drainage is practical, and other measures must be employed to prevent heaving. Pervious blankets of sand and gravel or other material are most commonly used to prevent frost-heaving. These layers vary in thickness between 1 and 4 feet, depending on heaving characteristics of underlying soil, depth of frost penetration, and height of capillary rise in the pervious material. Where thin gravel layers are used, measures should be taken to prevent fines from penetrating into the gravel, thereby increasing its capillarity. Such pervious layers should be maintained free of possible surface seepage from open drainage ditches, as well as free from ground water. Consideration should be given to the fact that the depth of frost penetration will be increased by snow removal from runways, and where possible frost data should be obtained from highways which are regularly maintained throughout the winter season.

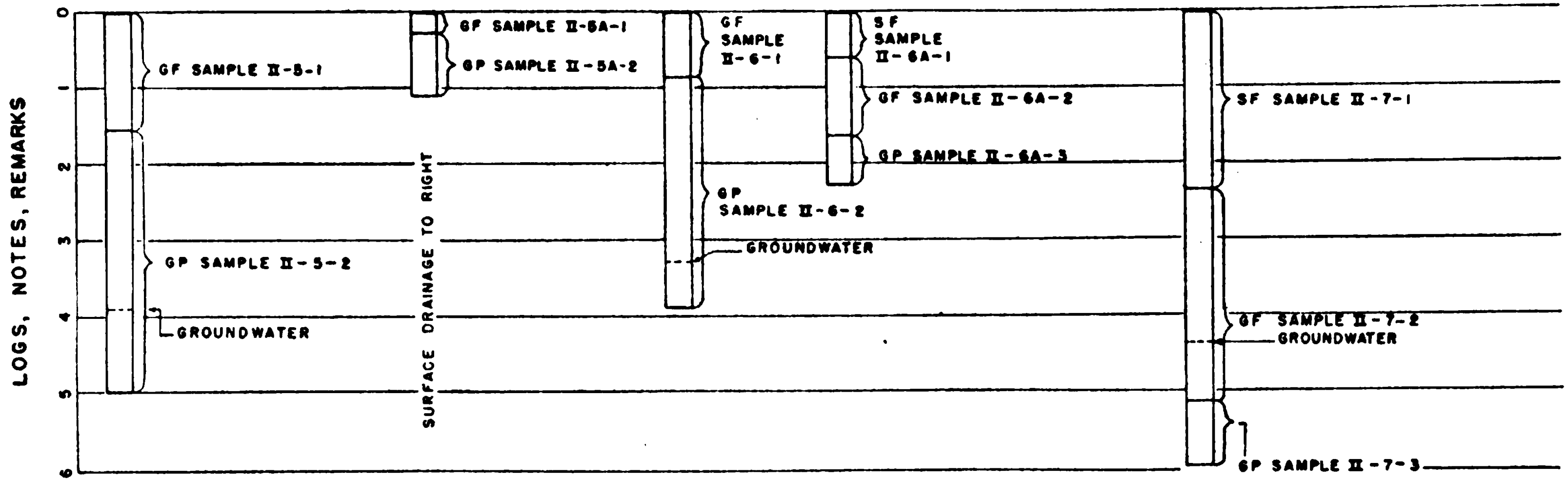
SECTION IX

SOIL SURVEY

Paragraph
Field exploration at site ---------- 32
Taking samples ---------- 33
Exploration for base and surface materials ---------- 34

32. Field exploration at site.—*a*. Purposes of field exploration at a site are to obtain soil samples for inspection, classification, and testing; to develop soil profiles; and to determine field drainage characteristics, location of water table, and proximity of ledge rock. It must be of such scope that thorough study can be made of all factors affecting design, treatment, and construction of subgrades and base courses. Exploration should consist of geological reconnaissance, augering, excavation of test pits, taking of soil samples, and observa-


SOIL PROFILE-AIRDROME
Date
Sheet 2 of 5
TEST HOLE No II-7
NATURAL GROUND SURFACE
SF (CUT)
GF
TEST HOLE No II-6A
TEST HOLE No II-6
RUNWAY SUBGRADE LINE + 0.44%
(FILL)
GP
APPROXIMATE WATER TABLE
TEST HOLE No II-5A
TEST HOLE No II-5
SHEET 1
SHEET 2
ELEVATION
STATION NUMBER ALONG RUNWAY


LOGS, NOTES, REMARKS
0
1
2
3
4
5
6
GF SAMPLE II-5-1
GP SAMPLE II-5-2
GROUNDWATER
GF SAMPLE II-5A-1
GP SAMPLE II-5A-2
SURFACE DRAINAGE TO RIGHT
GF SAMPLE II-6-1
GP SAMPLE II-6-2
GROUNDWATER
SF SAMPLE II-6A-1
GF SAMPLE II-6A-2
GP SAMPLE II-6A-3
SF SAMPLE II-7-1
GF SAMPLE II-7-2
GROUNDWATER
GP SAMPLE II-7-3

NOTE: INDIVIDUAL TESTHOLE SAMPLES OF SF, GF, AND GP SOILS ARE COMBINED TO FORM COMPOSITE SAMPLES OF THE THREE MATERIALS. EACH COMPOSITE SAMPLE IS REDUCED TO CONVENIENT SIZE BY QUARTERING AS PER APPENDIX III, PARAGRAPH 38

FIGURE 197.—Section of typical soil profile sheet.

tion of ground-water and drainage conditions. The extent of the exploration is governed by time available and character of soil formations. Where nonuniform soil conditions occur, a sufficient number of auger holes or test pits should be made to develop soil profiles along the edges of runways and at other locations where drainage is a problem. Auger holes along each runway should be spaced about 1,000 feet apart, with intermediate holes at critical points to complete the soil profile. Holes should be 6 inches in diameter and should extend about 4 feet below runway subgrade. A few holes should be carried to considerable depth to determine characteristics of the lower strata. Fewer auger holes will suffice if soil is uniform over the airdrome site.

b. Soil profile sheets (fig. 197) are developed as the soil survey progresses in the field. Subsequently laboratory test data are added to the soil profile sheets. If desired, a soil map of the airdrome site may be developed by combining soil profile data on a topographic map overlay.

33. Taking samples.—*a.* Soil samples should be taken from auger holes and test pits for visual inspection, classification, and testing. All samples must be representative of the deposit from which they are taken. (See pars. 36, 37 (app. III).) Careful field notes are kept to identify all samples.

b. Samples taken for classification tests are placed in cloth bags or cans with an identifying tag both inside and out. Samples taken for determining natural moisture content should be placed in containers which can be sealed. If undisturbed samples for density determinations and bearing ratio tests are taken, a metal cylinder 6 inches in diameter and 6 inches long is used. A cutting edge is provided at one end of the cylinder. The cylinder is pressed into the soil while the soil from around the outside is carefully removed. Ends of the sample are carefully trimmed to the rim of cylinder. Samples for density tests should be taken as described in paragraph 47 (app. III).

34. Exploration for base and surface materials.—Materials for base and surface courses may consist of natural soils or processed materials such as crushed stone, gravel, or shells. Exploration for these materials should include location and determination of quantity of all deposits of soil and rock. Auger holes and test pits should be dug at the most favorably located deposits of suitable material to determine quantity available and to obtain samples for classifications and other tests. Samples for testing are tagged and placed in cloth bags.

SECTION X

SOIL PROFILE

Paragraph
Soil profile -- 35

35. Soil profile.—Results of the field explorations during the soil survey and data from laboratory investigations of samples are summarized on a soil profile. Figure 197 illustrates a portion of a soil profile along one edge of a runway.

SECTION XI

SOIL TESTING

Paragraph
Representative samples -- 36
Sampling -- 37
Quartering samples -- 38
Laboratory tests -- 39
Grain-size distribution --- 40
Moisture-content determination -- 41
Liquid limit (LL) --- 42
Plastic limit (PL) -- 43
Plasticity index (PI) --- 44
Laboratory compaction and optimum moisture test (modified A. A. S. H. O.) --- 45
Bearing ratio and swell test (California) ---------------------------------- 46
Field density tests --- 47
Field and laboratory testing equipment -------------------------------------- 48

36. Representative samples.—Each sample for examination, identification, and tests must be representative of the deposit or supply from which it comes. Validity of all interpretations, conclusions, and designs based upon test results depends upon the accuracy with which the sample represents the whole.

37. Sampling.—*a. Test pits and gravel banks* are sampled by channeling. A cloth or paulin to collect the sample is placed at the bottom of the pit next to the bank. A hand shovel or pick is used to dig a vertical channel from top to bottom of the face being sampled until 50 or 100 pounds of material are collected. Overburden that will be wasted is not included. The collected sample is identified, tagged, and placed in a bag. Generally sand and earth deposits can be sampled satisfactorily by auger holes, provided overburden is excluded or kept in separate containers.

b. Aggregate already in bins is difficult to sample properly. Better samples may be taken as aggregate spills from conveyor belt into bin by passing a bucket completely through the stream of falling material. Several samples should be taken in this manner and combined for subsequent reduction by quartering. Samples also may be taken from spout or loading chute as material is discharged from bins into trucks.

c. Stockpiles may be sampled by uniform surface channeling as are test pits. The channel must extend from bottom to top because stockpiles always have a preponderance of coarse aggregate at the outside bottom edges and a deficiency of coarse aggregate at the top. Stockpiles built up in layers by truck dumping may be sampled by digging well into the pile from the top.

d. Windrows are sampled by taking and combining equal amounts selected from top, center, and bottom, well within the stack each time.

e. Samples from material in place on the runway are obtained by combining spot samples selected over the area.

38. Quartering samples.—*a.* It frequently is necessary to reduce a large representative sample to a smaller convenient size without sacrificing representation. The process is called quartering. The total collected sample first is piled in a cone on a canvas or paulin, each shovelful going to the center of the cone and being allowed to run down equally in all directions to mix the sample. The cone then is spread out in a circle by walking around the pile and gradually widening the circle with a shovel until the material is spread to a uniform thickness. The flat pile then is marked into quarters. Two opposite quarters are discarded. The material remaining in the two quarters is again mixed by shoveling the material into another conical pile, taking alternate shovelfuls from each quarter. The process of piling, flattening, and rejecting two quarters is continued until the sample is reduced to the desired size.

b. Small samples are quartered by essentially the same process but are mixed by rolling instead of by piling. The total collected sample is placed on the canvas or paulin. Each corner of the canvas is lifted in turn and pulled back over the canvas as if preparing to fold it on a diagonal. After thorough mixing the sample is flattened and quartered as before. This procedure is especially useful in the laboratory for selecting small representative test samples.

39. Laboratory tests.—The laboratory tests performed to determine physical characteristics and constants of subgrade, base, and surface course materials are: sieve analysis, moisture content determination, compaction test (modified A. A. S. H. O. method), density test, and bearing ratio (California). Fine-grained soils may require a wet analysis in addition to sieve analysis. Extent of the testing program will depend upon type of soils and experience of the soil technician. All classification tests will not be required after the technician becomes thoroughly acquainted with the soils of a locality. Significance and procedure of classification tests are described in the following paragraphs.

40. Grain-size distribution.—Grain-size distribution of a soil is determined either by sieve analysis or by a combination of sieve and wet analysis. Sieve analysis aids in classification of soils, determination of percentage of fines, and in study of gradation, which, correlated with descriptions as given in paragraphs 4 to 9, inclusive (app. III), will be helpful in judging physical characteristics. Procedures used to determine gradation are as follows:

a. Sieve analysis.—A sieve analysis is used to determine gradation of material containing a substantial portion of gravel and sand sizes. *If the sample has very little fine material*, so that dry sieving will give good particle separation, the procedure is:

(1) Select a representative sample weighing between 200 and 500 grams (depending upon the percentage of gravel particles).

(2) Dry the sample and record the dry weight.

(3) Put the dry sample in stack of sieves consisting of 1-inch, ¾-inch, Nos. 3, 4, 10, 40, 60, 100, 200, and pan. Place the cover on the stack and shake the stack vigorously with a horizontal rotating motion and occasional jarring on a *buffer* or *pad* until the particles have been separated.

NOTE.—Sieves may be added or omitted from this series as needed or desired. Because the No. 200 sieve is delicate and easily damaged, it is always protected by having a coarser sieve such as No. 40 or No. 60 on top of it.

(4) Starting with the top sieve (largest) determine the weight of particles on each sieve and in the pan. Record the results as in table XXXIII. Save each part of the sample until a check has been made by comparing the sum of the weights with original dry weight ((2) above).

(5) Results are computed as in table XXXII and plotted as in fig. 4 which is 5-cycle semilogarithmic paper with the abscissa plotted as "sieve opening" or "grain diameter" in millimeters or inches and the ordinate as "percent finer." See table LIV for sieve dimensions.

(6) *If the sample has such a proportion of fine material that dry sieving will not be accurate*, prewashing is necessary. The procedure then is:

(*a*) Select a representative sample as above.

(*b*) Dry the sample and record the dry weight.

(*c*) Wash the sample on a No. 100 sieve, being careful not to lose any of the material retained on the sieve.

(*d*) Dry the portion retained on the No. 100 sieve and record its weight. Difference between the original dry weight ((2) above) and the dry weight after washing is recorded as the weight passing No. 100.

(*e*) Shake the washed sample through sieves as above.

(*f*) Weigh and record results as above. Sum of all weights, including the weight passing No. 100 from (4) above should check with the original dry weight in (2) above.

(*g*) Compute and plot results as above.

TABLE XXXIII

Sample identification........ .. ..

Sieve	Weight retained on each sieve in grams	Percent retained by weight	Cumulative percent finer than each sieve	Sieve	Weight retained on each sieve in grams	Percent retained by weight	Cumulative percent finer than each sieve
1 in............	35	7	93	No. 100.........	40	8	7
½ in............	85	17	76	No. 200.........	15	3	4
¼ (No. 3)......	90	18	58	Passing 200.....	20	4	.....
No. 4...........	45	9	49				
No. 10.........	75	15	34	Total.....	500	100	
No. 40.........	95	19	15				

b. Wet analysis.—This is not a routine test. Laboratory equipment for this test is included in the heavy construction set in depot stock; it is not included in the battalion set. Its use will be required only for special studies of subgrade soils. Wet analysis is used to determine gradation of fine soils composed of particles passing the No. 100 mesh sieve, and is based on the fact that soil grains of the same material, but of different sizes, will fall through water at different velocities. Equipment required includes a 1000-cc graduated cylinder provided with a side petcock at a distance from 15 to 25 cm below the 1000-cc graduation. A small representative portion of the soil sample is uniformly dispersed in water in the graduate and set in a vertical position. At selected intervals of time, density of the suspension at the level of the petcock is determined by removing part of the suspension. From this density and the density at the beginning, percentage of soil remaining in suspension at the depth of the petcock below the water surface can be computed by Stokes' law. Velocity of fine grains of soil falling through a water medium according to Stokes' law is: $V=\frac{2}{9}\times\frac{S-So}{n}\times\left(\frac{d}{2}\right)^2$. S and So are specific gravities of soil and liquid respectively, n is viscosity of the liquid, and d diameter of the soil grain assumed to be spherical. For purpose of a wet analysis, sufficiently accurate results can be obtained by using the formula: $V = 9{,}000\,d^2$ wherein d is in centimeters and v in centimeters per second. This formula is derived from Stokes' law by substituting the following:

$S = 2.67$
$So = 1$ (water)
$n = 0.0000103$ gram-sec. per sq. cm (water at 20° C.)

Using the formula ($v = 9{,}000\,d^2$) curves on figure 5 have been drawn showing distances through which different sized soil particles will fall in a given time period. The following procedure is used:

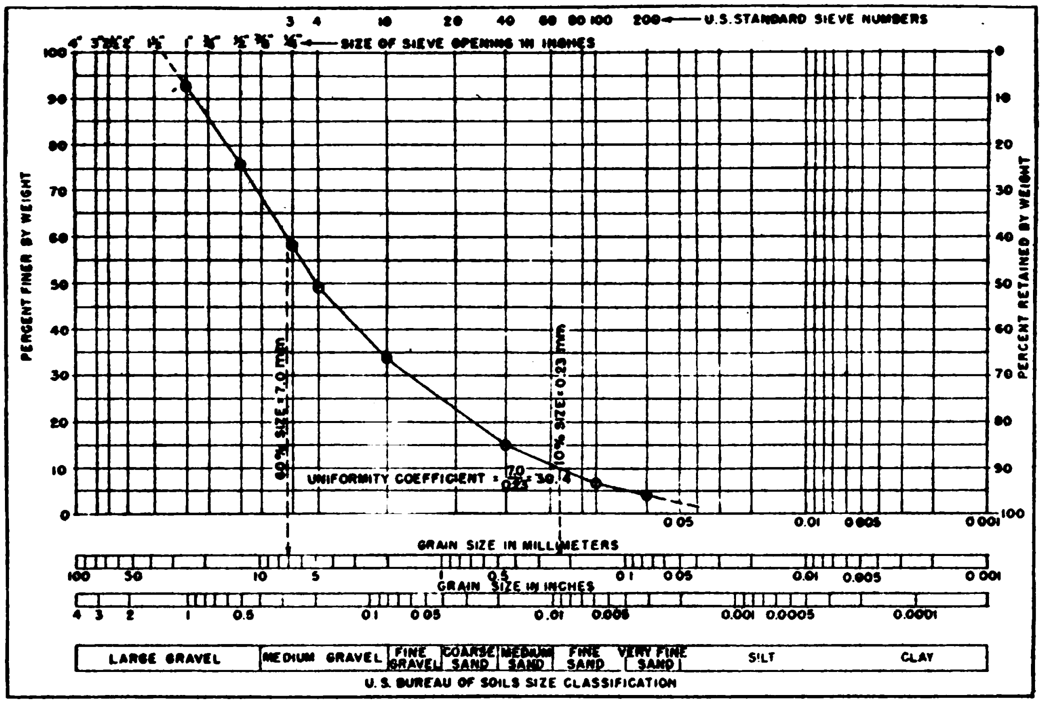


FIGURE 198.

(1) Select a representative sample of the soil passing No. 100 sieve.

(2) Thoroughly dry and weigh from 50 to 100 grams of the sample.

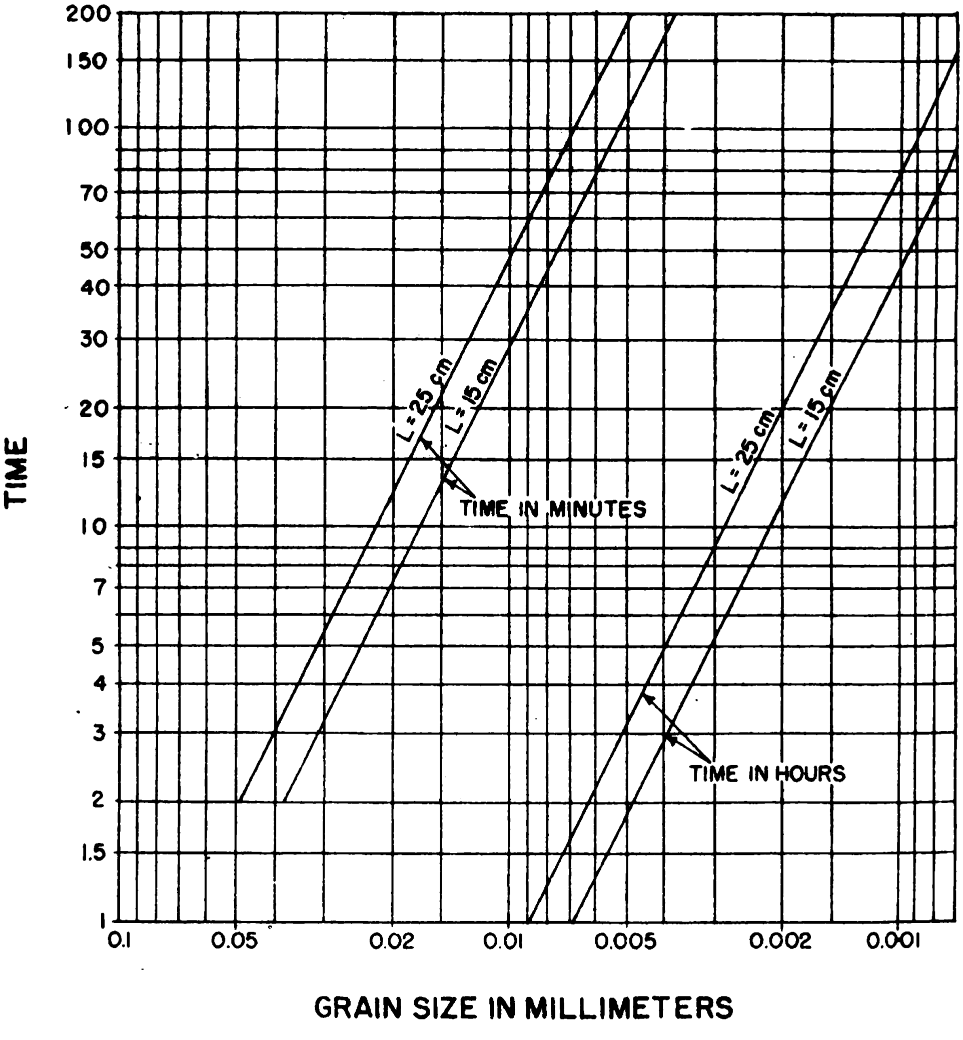
(3) Disperse the specimen in water in a 1000-cc graduate cylinder and fill the cylinder to 1000-cc graduation. It is necessary to disperse the soil thoroughly by stirring or shaking, taking care not to spill any of the suspension. Water temperature should be at room temperature.

(4) If the soil particles flocculate (form clusters) from 5 to 10 cc of sodium silicate should be added during the dispersion process.

(5) Shake cylinder to produce a uniform suspension and set in

a vertical position at a noted time. Thereafter the cylinder should not be disturbed. Temperature of cylinder should be maintained reasonably constant near room temperature.

CURVES SHOWING RELATION BETWEEN GRAIN SIZE, TIME AND SETTLEMENT DISTANCE BASED ON STOKES LAW FOR AVERAGE TESTING CONDITIONS.



L=SETTLEMENT DISTANCE IN CENTIMETERS

Figure 199.—Wet analysis.

(6) Measure the distance *L* from the center of the petcock to the water surface in centimeters.

(7) Determine from the curves in figure 199 the time required for a certain sized particle to fall through the distance *L*.

(8) After the required time period, draw off through the petcock approximately 100 cc of suspension.

(9) Determine dry weight of soil in the drawn-off suspension by evaporating water and weighing soil residue.

(10) Compute percentage of soil finer than the grain size selected in (7) by the following formula: $P=\frac{V_1}{W_1}\times\frac{W_2}{V_2}\times100$ (in percent) in which—

W_1=Initial total dry weight of soil in grams
V_1 =Initial volume in cubic centimeters of suspension
W_2=Dry weight in grams of soil in suspension drawn off through petcock
V_2 =Volume in cubic centimeters of suspension drawn off through petcock

(11) Repeat steps (6) through (10) to determine percentage finer than particles of any other size. Usually, the percentage finer than three sizes may be determined. It should be noted that L changes for each determination, but W_1 and V_1 are constant.

(12) Plot the data as described in *a* above.

TABLE XXXIV

Sample identification ____________________

Sieve	Weight retained on each sieve in grams	Percent retained by weight	Cumulative percent finer than each sieve
Sieve analysis:			
1-in	0	0	100
½-in	100	20	80
¼-in (No. 3)	85	17	63
No. 4	35	7	56
No. 10	35	7	49
No. 40	25	5	44
No. 100	20	4	40
Passing 100	200	40	
Total	500	100	

Sieve	Distance L in cm	Time	Dry weight grams	Percent finer *
Wet analysis:				
Finer than 0.03 mm	25	5 min. 20 sec	1. 60	32
Finer than 0.01 mm	20	38 min	1. 10	22
Finer than 0.004 mm	15	170 min	0. 65	13
Original sample			50. 0	

* Computed from formula $P=V_1/W_1\times W_2/V_2\times100$ (in percent)

c. Combined analysis.—Combined analysis is used when it is desired to have a complete grain-size distribution curve for materials containing gravel, sand, silt, and clay sizes. The soil is usually washed through a No. 100 sieve to separate fine and coarse fractions. Separation for some soils may be obtained satisfactorily by dry sieving. Gradation of material passing the No. 100 sieve is obtained by wet analysis as described in *b* above, and gradation of that retained on the sieve by sieve analysis as described in *a* above. Results are combined to determine percentage of grains finer than a given size, based on the total dry weight as illustrated in table XXXIV. Results are plotted as described in *a* above. (See fig. 200.)

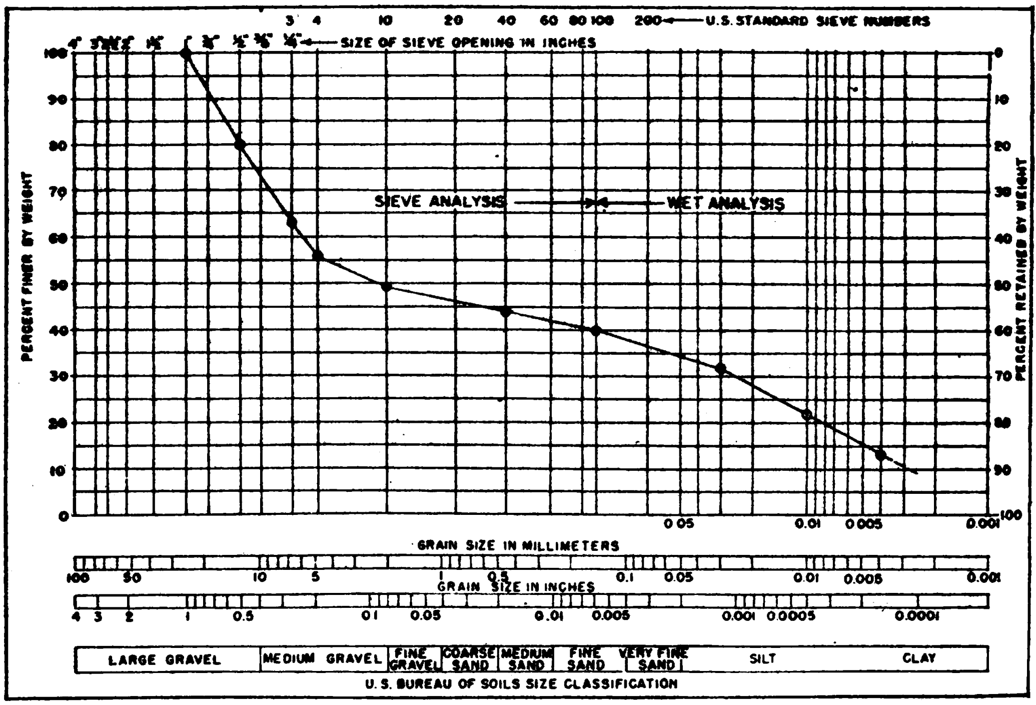


FIGURE 200.

41. Moisture-content determination.—Moisture contents of natural and compacted subgrade, compacted fill, and base-course materials should be determined for the purpose of design and for control of compaction during construction. Moisture-content determinations are also required for the bearing-ratio, expansion, density, compaction, liquid-limit, and plastic-limit tests. Moisture content is expressed in percentage of dry weight of the soil. In general, determinations are made by placing a representative specimen of the wet soil in a metal container and thoroughly drying the specimen in an oven. If the soil is free from organic and other combustible matter, the specimen may be dried over a fire. The wet weight of the specimen prior to heating and the dry weight having been determined, the moisture content may be computed by the formula:

$$P=\frac{W_w-W_d}{W_d}100 \text{ (in percent)}$$

P= Moisture content in percent of dry weight
W_w= Wet weight of sample
W_d= Dry weight of sample

42. Liquid limit (LL).—*a.* Liquid limit is defined as the moisture content expressed as a percentage by weight of oven-dry soil, at which a remolded soil will just begin to flow when jarred slightly. Liquid limit in conjunction with plastic limit is of great value in proper identification and classification of fine-grained soils in remolded state.

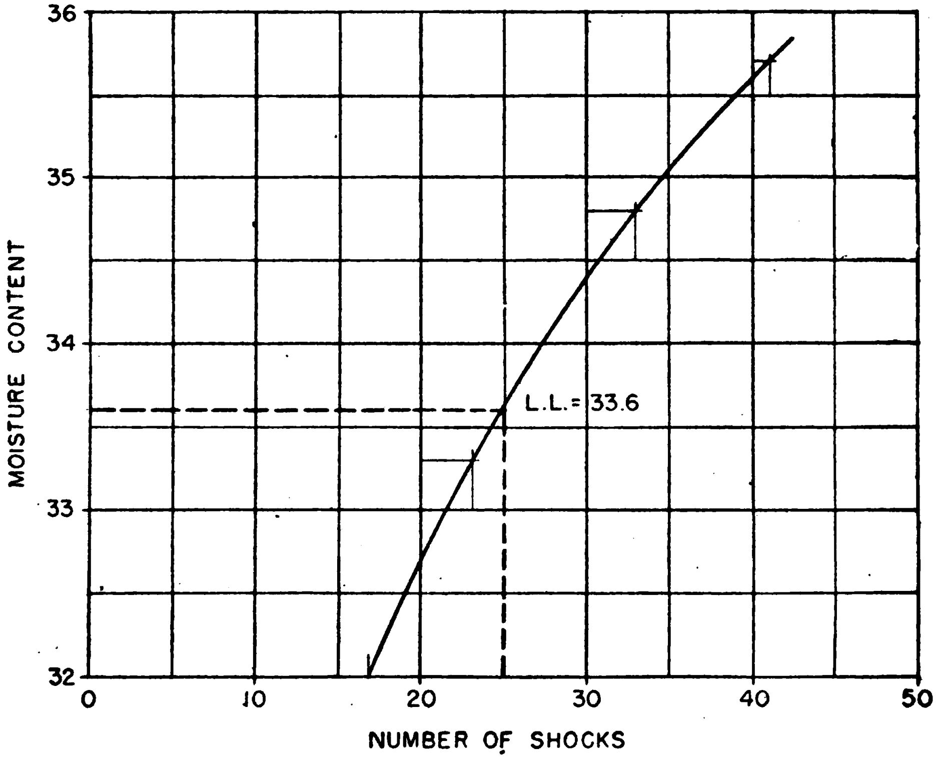


FIGURE 201.—Graph for determining liquid limit.

b. The device used to determine liquid limit consists of a mechanism for producing uniform blows on the bottom of a dish. The test should be performed by using a representative sample of the fraction of soil passing the No. 40 sieve. Approximately 50 to 80 grams of the sample are thoroughly mixed with water to form a heavy paste and placed in the dish. The soil is grooved with a special tool which is drawn through the soil specimen along a diameter of the cup passing through the center of the hinge. In cutting the groove, the tool should be held perpendicular to the surface of the dish. Shoulders of the tool should remove soil for a length of about 1½ inches when the dish is properly filled. In clays, a clean groove can generally be made with one stroke of the tool. In silty soils, however, it may be necessary to cut the groove with several strokes of the tool or by means of a spatula, using the tool to check the dimensions.

c. After the soil is placed in the dish and the groove properly formed, the crank of the liquid-limit device is turned at the approximate rate of two revolutions per second. The number of blows required to close the bottom of the groove for a distance of half an inch is determined. Part of the specimen is placed in a metal container and the moisture content is determined as described in paragraph 41 (app. III). The above procedure is repeated at various moisture contents. A graph (fig. 201) is plotted showing the relation between moisture content and number of blows required. The water content corresponding to 25 blows obtained from the graph is defined as the liquid limit. (If plotted on semilogarithmic paper the graph will be a straight line.)

43. Plastic limit (PL).—*a.* Plastic limit is defined as the lowest moisture content, expressed as percentage of the dry weight, at which soil can be rolled into threads of ⅛-inch diameter without crumbling. Plastic limit is the moisture content at which cohesive soils pass from a semisolid to the plastic state. Thus, if natural moisture content of a soil is less than the plastic limit, the soil possesses relatively high stability.

b. The test is performed on a representative sample of the soil fraction that passes the No. 40 sieve. A sample of the soil is thoroughly mixed with water to form a plastic mass at a moisture content somewhat above the plastic limit. A specimen about the size of a ½-inch cube is removed from the plastic sample and rolled on a flat nonabsorbent surface with the palm of the hand, forming a roll about ⅛-inch diameter. If crumbling does not occur at that moisture content, fold, knead, and reroll as before. Repeat this process until water content is reduced to the plastic limit, which is reached when crumbling occurs as soil is rolled out to a diameter of about ⅛-inch. Moisture content of the sample at plastic limit is determined as stated in paragraph 41 (app. III). (Some soils cannot be rolled into threads at any moisture content. Such soils do not have a plastic limit as above defined. Test results are reported as nonplastic (NP).)

44. Plasticity index (PI).—Plasticity index is defined as the difference between liquid limit and plastic limit. It is determined by taking the numerical difference between the two values. For example, if the liquid and plastic limits of a soil are 28 and 24 respectively, the plasticity index is 4. A cohesive soil with a low plasticity index has better stability than one with a high value. Nonplastic (NP) soils that have no plastic limit have a plasticity index of zero.

45. Laboratory compaction and optimum moisture test (modified A. A. S. H. O.).—*a.* Density to which a soil may be compacted with a given compaction effort depends upon the moisture content as described in section VII (app. III). Moisture content at which the greatest density is obtained with a given compaction effort is termed "optimum moisture." It should be noted that optimum moisture is not a constant for a given soil, but is variable, depending upon amount of compaction effort. Optimum moisture decreases with an increase of compaction effort and in general is such that air content of the soil (unfilled voids) is from 2 to 8 percent by volume, depending upon characteristics of the soil.

b. In runway pavement construction, it is desirable to compact subgrade fill, upper zones of subgrade cuts, and base course materials to as great a density as is practicable in order to obtain greatest stability and prevent detrimental settlements. It has been found that the maximum density that can be obtained in actual construction, using ordinary heavy compaction equipment, can be closely duplicated in the laboratory by the modified A.A.S.H.O. test procedure.

c. Special equipment required to make the laboratory compaction test consists of a metal tamper with a striking face 2 inches in diameter, weighing 10 pounds, and a Proctor cylinder. The Proctor compaction cylinder is a metal cylinder having an internal diameter of 4 inches and a height of 4.59 inches. Volume of the cylinder is $\frac{1}{30}$ of a cubic foot. The cylinder is provided with a removable baseplate and a removable extension of the cylinder having the same internal diameter as the cylinder and approximately 2½ inches in height.

d. Procedure of the laboratory compaction test (modified A.A.S.H.O. method) is as follows:

(1) Air-dry a sample weighing approximately 6 pounds and remove all material not passing a ¼-inch (No. 3) sieve.

(2) Determine and record tare weight to 0.05 pound of the Proctor cylinder with attached baseplate but without the extension.

(3) Thoroughly mix sample with a sufficient quantity of water to obtain a damp mixture. Care should be taken not to add too much water.

(4) Fill the Proctor cylinder (with extension attached) in five equal layers (each layer about 1 inch thick after compaction), com-

pacting each layer by dropping the tamper 25 times. Height of drop should be 18 inches above the soil and blows should be distributed over the soil layer surface.

(5) Carefully remove extension and level off top of soil with a straightedge.

(6) Determine unit wet weight (U_w) of compacted soil in pound per cubic foot.

(7) Remove soil from cylinder, extract a sample from the center weighing about 100 grams, and determine its moisture content (P) as in paragraph 41 (app. III).

(8) Compute unit dry weight (U_d) compacted soil using data in (6) and (7) above.

$$U_d = \frac{100 \times U_w}{100 + P} \text{ (in lbs. per cu. ft.)}$$

(9) Thoroughly remix the remainder of the sample, adding sufficient water to increase water content from 1 to 2 percent, and repeat the above steps.

(10) Repeat procedure as outlined above until points beyond maximum density have been obtained.

(11) From density thus obtained, prepare a curve as in figure 202, showing the relation between moisture content and unit weights, dry and wet. (Unit weight as ordinate.) The peak of the curve defines the optimum moisture and maximum density (Max. U_d) that should be used for compaction control during construction.

e. Difficulties may be encountered with above procedure if the soil is very uniform fine sand. A soil must contain sufficient binder or be sufficiently well graded to prevent upheaval during blows of the tamper. Otherwise, tamping procedure should be modified so that initial stability is produced by lighter blows before the standard blows are applied.

f. It should be noted that only material passing the ¼-inch (No. 3) sieve is used in the test. Thus, optimum moisture and unit dry weight as obtained from the test are not representative of the total material if it contains any considerable amount of gravel particles. For control during construction, it is necessary to determine unit weight and moisture content only of material passing the ¼-inch sieve. Stones greater than ¼ inch should be removed from specimens used for moisture-content determinations. Unit weight can be determined by adjusting unit weight of the total sample according to percentage by weight and volume of particles greater than ¼ inch in diameter in the soil.

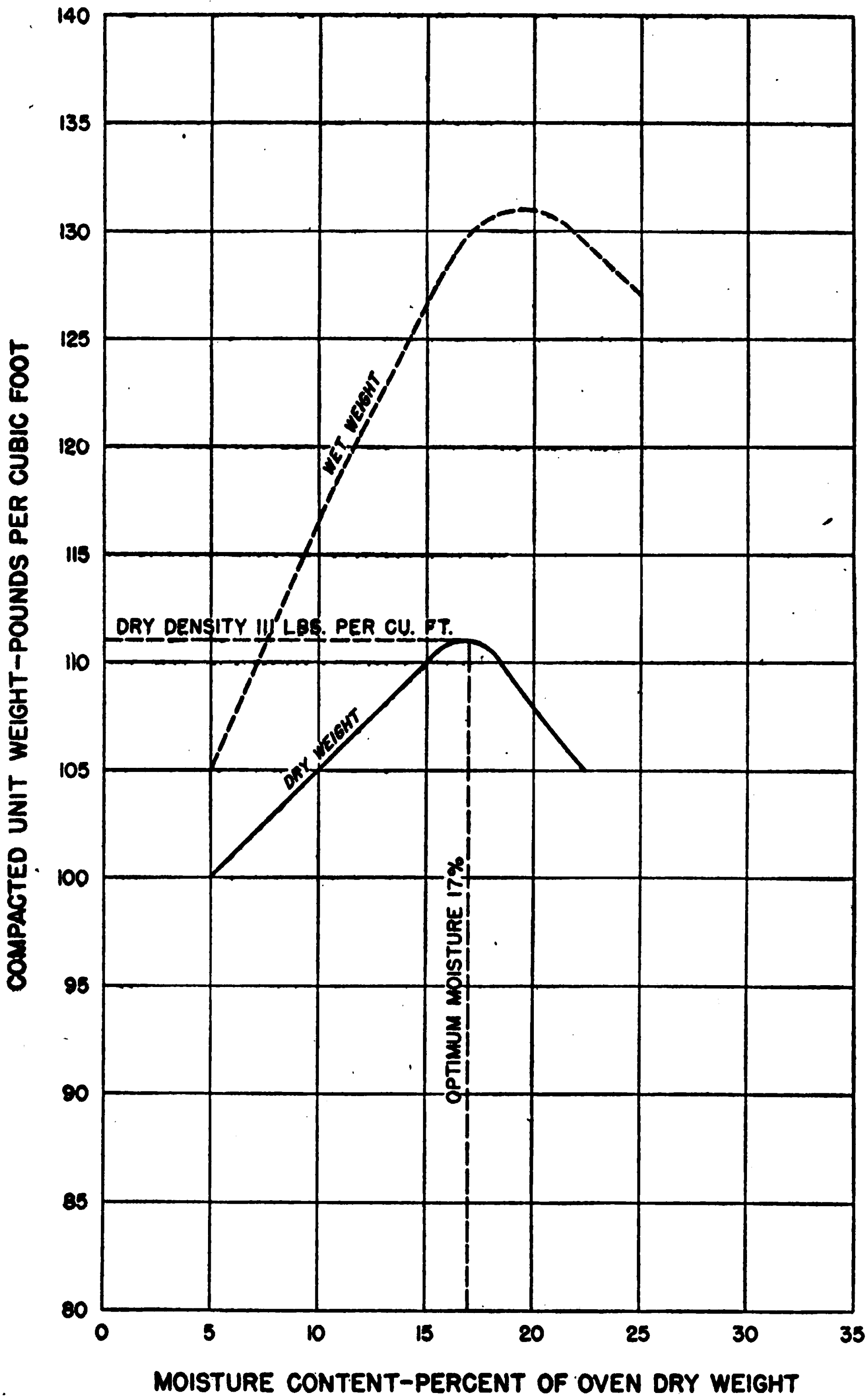


FIGURE 202.—Unit weight curves of soil.

46. Bearing ratio and swell test (California).—*a.* The California Division of Highways has developed an empirical method for designing flexible highway pavements which employs a test termed "bearing ratio." This is a measure of the bearing or load capacity of a subgrade or base material. The empirical data have been extended for use in airdrome pavement design, for which purpose some modifications of the original test procedure have been found necessary. Bearing ratio is load intensity required to produce 0.1 inch penetration of a piston 1.954 inches in diameter (3 sq. in.) into a soil, divided by load intensity required to push the same piston into a standard sample of compacted crushed stone for a distance of 0.1 inch. Bearing ratio is expressed as a percentage. For designing thickness of various base courses, bearing ratio should be determined for all subgrade soils and base course materials. *Soils should be tested at a density comparable to that obtained in construction* (see pars. 27 and 47 (app. III)). In a few cases, where the airdrome pavement will be used only for a short period during favorable weather, samples should be tested at natural moisture content. In all other cases samples are tested in a saturated condition, especially when the airdrome is to be used in all seasons of the year.

b. Equipment used consists of a metal cylinder similar to a Proctor cylinder (see par. 45 (app. III)) except that it is 6 inches in diameter, buckets in which soil sample is saturated, a loading device to force the piston into the soil, and attachments. Procedure for determining bearing ratio of a compacted subgrade or base course soil is as follows:

(1) Determine optimum moisture of the soil as described in paragraph 45 (app. III), using part of the soil sample.

(2) From the rest of the sample, remove all material over ¾-inch in size and replace with an equal weight of material between the ¼-inch (No. 3) sieve and ¾-inch size.

(3) Compact the prepared soil in California test cylinder at optimum moisture content using procedure described in paragraph 45 (app. III), except 55 blows in place of 25 blows of the tamper per layer should be used to compensate for the additional area. After removing the collar, carefully strike off the surface and smooth it. The baseplate is then removed from the bottom, attached to the other end of the cylinder, the specimen is inverted, and the collar is replaced.

(4) Place a filter paper on the undisturbed exposed surface of the specimen, then place perforated plate with adjustable stem on the filter paper. Next add two 5-pound lead weights on the plate.

(5) Immerse sample with weights applied, and measure amount of swell by means of tripod gage. Sample should be soaked for 4 days

unless satisfactory saturation can be obtained in a shorter period. Express expansion or swell of the specimen in percent of the original height of 6 inches.

(6) Allow drainage for 15 minutes after soaking before penetration test is run.

(7) For granular subgrade soils, apply a confining unit load of lead weights around the piston, approximately equal to the load intensity to be produced by the base and surface courses which will overlie the subgrade represented by sample. (It will be necessary to estimate required load; if the load does not agree with final design, check tests will be required.)

(8) Seat penetration piston with 10-pound load and set load gage to zero before starting test.

(9) Apply load on penetration piston so that the rate of penetration is approximately 0.05 inch per minute.

(10) Determine load required to produce a penetration of 0.1 inch.

(11) Compute bearing ratio (Br) using formula—

$$Br=\frac{Lt}{Lc}\times 100=\frac{Lt}{30}\text{ (in percent)}$$

in which

Br=Bearing ratio.

Lt=Total load in test to produce 0.1 inch penetration.

Lc=Total load to produce 0.1 inch penetration in compacted standard crushed stone sample determined by test to be 3,000 pounds (1,000 lbs. per sq. in.).

(12) The average of two tests should be taken as the bearing ratio of the soil provided the results are reasonably consistent. If not consistent, check tests should be made.

(13) Steps, (5) to (10), inclusive, above may be used to test soil placed in any state in the cylinder. If it is desired to conduct tests on undisturbed samples, the soil sample should be taken with the 6-inch diameter sampling cylinder equipped with the cutting edge. The sampling cylinder is later used as the testing cylinder.

47. Field density tests.—Determination of density of samples taken during construction is necessary to control compaction in the field. During the first few days of compaction of a subgrade or base course, numerous density samples should be taken and tested and the results should be compared with the densities obtained by the laboratory compaction test (see par. 45 (app. III)). Comparison is made on the basis of dry weight per cubic foot. The wet weight per cubic foot of compacted soil in the field (U_{fw}) is determined by one of the methods given below. The moisture content of the field sample (P_f) is determined as in paragraph 41 (app. III). Then the unit dry weight (U_{fd}) of the field sample is:

$$U_{fd}=\frac{100\times U_{fw}}{100+P_f}\text{ (in lb. per cu. ft.)}$$

The percent compaction (density) of the field sample as compared with maximum density in the laboratory compaction test (par. 45 (app. III), and fig. 202) is:

$$\text{Percent compaction (density)}=\frac{100\times U_{fd}}{\text{Max } U_d}$$

If sufficient compaction is not obtained, more passes or heavier equipment should be used. For example the weight of sheepsfoot roller can be increased by adding water to the drums. After a satisfactory field compaction procedure is established, it is not necessary to check compacted soil density unless different soils are encountered. However, until optimum moisture content can be determined by feel and visual characteristics, moisture content determinations should be made to insure that soil contains the proper moisture for compaction. Several methods are used to determine density of soil *in situ* (in place). The method to be used will depend upon type of soil and experience of sampling personnel. Acceptable methods are as follows:

a. Cylinder.—The cylinder method may be used for uniform fine sands, silts, or clays, which do not contain gravel particles. The equipment consists of a metal cylinder, 6 inches in diameter and 6 inches long, equipped with a cutting edge. As the cylinder is pushed into the soil, it is usually necessary to remove the soil from around the cylinder to relieve restraint. After the cylinder is full, the top surface is trimmed with a steel straightedge. A plate is placed on the top of the cylinder and the cylinder with the soil is inverted. The other soil surface is trimmed so that volume of the soil equals volume of the cylinder. The sample is placed in a clean container for weighing or for drying and weighing.

b. Oil.—The oil method may be used in soils sufficiently impervious to prevent any seepage of the oil into the soil during period of the test. Any type of oil, such as crank case oil, may be used. Prior to sampling, weight per cubic foot of the oil and weight of oil in the container are determined. In the field, the surface of the soil is smoothed and leveled for an area of about 12 inches in diameter. In the center of the area, a hole is dug by hand or with a 6-inch auger, taking special care to place all of the soil in a clean container, to be later dried and weighed. After the hole is cleaned, it is rapidly filled with the oil so that the volume of the oil equals the volume *in situ* of the soil removed. The weight of the oil used to fill the hole is determined. The volume may be computed from this.

c. Sand.—The sand method may be used in any type of soil. The method is the same as the oil method described above, except clean sand is used. The sand is dried thoroughly in the laboratory and placed in covered containers. Unit weight of the sand when placed is determined by a definite procedure. Usually the sand is poured through a funnel held at a constant height above the sand surface. Care must also be taken to prevent the sand from absorbing any moisture, since a small amount will cause bulking of the sand.

d. Chunk.—The chunk method may be used for soils which are sufficiently cohesive to form a chunk when removed. The method consists of determining the volume of a chunk of soil in the laboratory by the immersion method. A chunk of soil is removed in the field and taken to the laboratory. If the soil is sufficiently dense and cohesive, the volume is obtained by first weighing it in the air and then weighing it when immersed in water or oil. For most soils, it is necessary to coat the chunk with paraffin to prevent breaking or crumbling. The paraffin coat is applied with brushes either in the field or laboratory. If the soil has little cohesion and cannot be removed as a chunk, a pedestal is formed which is parafin-coated with brushes, or paraffin is poured around the pedestal using a cylinder as a mold. Volume of the paraffin sample is determined by the immersion method in the laboratory. After the volume is determined, the paraffin is peeled from the sample and placed in a pan of hot water and melted. As the water cools, clean hard paraffin is formed at the surface. Volume of the paraffin is determined by its weight and specific gravity (about 0.9). Volume of the soil is equal to volume of the paraffined sample, minus volume of the paraffin. Weight of the soil sample is determined after drying in an oven.

e. Water.—The water method is similar to the oil method except that a rubber membrane is used in the hole to prevent seepage into surrounding soil. The water method may be used in all types of soil. Volume of the soil removed equals combined volume of rubber membrane and water. Unit dry weight of the soil *in situ* can be determined by one of the above methods. If the soil is protected against loss of moisture until weighed, unit wet weight and moisture content can be determined. However, more satisfactory results can usually be obtained by determining moisture content on a separate sample. For gravelly soils, it is necessary to obtain unit dry weight only of material passing the ¼-inch sieve so that results can be compared with those obtained by the laboratory compaction method (par. 45 (app.

III)). Unit weight of material passing the ¼-inch sieve can be computed by reducing total dry weight and volume of sample by weight and volume of stones greater than ¼-inch. Volume of the stones can be determined by the immersion method.

48. Field and laboratory testing equipment.—Following is a list of items included in the laboratory set issued to engineer aviation battalions. Additional testing equipment is in depot stock primarily for use with heavy construction equipment sets or for other special purposes.

Quantity	Unit	Description
2	Each	Augers, post hole, 6-in.
6	do	Pipe, 4-ft. extensions for auger.
20	do	Bags, sample, canvas, 7 in. x 15 in. with drawstrings.
5	do	Bags, sample canvas, 17 in. x 32 in. with drawstrings.
1	do	Balance, torsion, "Harvard Trip" design. Capacity 4,500 gr.
1	do	Balance, triple beam, agate-bearing. Capacity 111 gr.
12	do	Blades, hacksaw.
12	do	Boxes, metal, seamless, round, flat bottom, with cover. Capacity 4 oz.
12	do	Boxes, metal, seamless, round, flat bottom, with cover. Capacity 8 oz.
4	do	Brushes, paint, flat (2 ea. 1 in. wide; 2 ea. 2 in. wide.)
1	do	Canvas, quartering, 5 ft. x 5 ft. with hemmed edges, 16 oz.
1	do	Chisel, wood, ¾ in. blade, 6½ in. long.
1	do	Cylinder, compaction, brass with collar, tamper (10 lb.) and tamper guide (2¼ in. inside diameter x 18 in. long). Capacity 1/30 cu. ft.
2	do	Cylinders, graduated, lucite. Capacity 120 cc.
2	do	Files, steel. Length 12 in. (1 mill, smooth, flat; 1 second cut, half round.)
1	do	Fillers, battery with rubber bulb.
3	do	Gage (indicator) dials with jeweled bearings, graduated to 0.001 in., spindle travel 1.000 in.
2	do	Knives, butcher, stainless steel.
100	do	Labels, paper, white, gummed.
1	Each	Machine, bearing ratio, California, complete with attachments and supplies: 1 ea. frame; 1 ea. jack, hydraulic; 1 ea. bracket, dial-gage; 1 ea. bumper, gage bracket; 1 ea. clamp, gage tripod; 6 ea. cylinders, compaction, steel, 6 in. inside diameter x 6 in. long; 6 ea. cylinder extensions; 2 ea. cutting edges for field sampling; 1 ea. piston, penetration, 1.954 in. diameter; 3 ea. plates, perforated, bronze with adjustable stem; 10 ea. weights, lead; 1 qt. oil, hydraulic jack; 1 box paper, filter, 15 cm diameter.

Quantity	Unit	Description
1	Each	Machine, liquid limit, with grooving tool.
3	do	Molds, cylinder, split, sheet metal, 2 in. diameter, 4 in. long.
2	do	Notebooks, field.
1	do	Oven, steel, two-burner.
5	do	Pails, galvanized, with wire bail. Capacity 14 qt.
24	do	Pans, enamel, round, flat bottom, 9 in. diam., 4 in. high.
12	do	Pads, paper, 5 in. x 8 in.
100	do	Paper, plotting, size 8½ in. x 11 in. rectangular coordinate.
50	do	Paper, plotting, size 8½ in. x 11 in. semilogarithmic, 3-cycle.
25	Pounds	Paraffin, 122° melting point.
12	Each	Pencils, 3H.
6	do	Pencils, china marking.
1	do	Pliers, long nose, side cutting, length 6 in.
1	do	Rules, measuring, stainless steel, graduated in inches, fractions one side, decimals other side.
2	do	Rules, measuring, steel, flexible, 6-ft. inclosed.
1	do	Scales, dial capacity 30 lb.
1	do	Scales, dial capacity 60 lb.
2	do	Screw drivers: one 4-in., one 8-in.
1	Set	Sieves, U. S. Standard, nested; each sieve half-height, 8 in. diam., 1⅝ in. high; with pan and cover: 1 ea. 1-in. opening. 1 do. ¾-in. opening. 1 do. ¼-in. opening (No. 3). 1 do. No. 4. 1 do. No. 10. 2 do. No. 40. 1 do. No. 60. 2 do. No. 100. 2 do. No. 200.
1	Each	Sieve, ¾-in. openings, steel frame with handles, size 18 in. x 18 in.
1	do	Sieve, ¼-in. openings, steel frame with handles, size 18 in. x 18 in.
2	do	Spatulas, 4-in. blade, wooden handle.
2	do	Spoons, steel, length 14 in.
2	do	Stoves, gasoline, two-burner, with windshield.
1	do	Straightedge, steel, length 12 in.
100	do	Tags, linen, shipping.
1	do	Thermometer, all-metal, range 0° to 150°C.
1	Set	Towels, cotton.
2	Each	Trowels, pointing, blade 5-in.
1	Ball	Twine, Seine, cotton.
1	Set	Weights, metric, nested, range 5 to 5,000 grams.
1	Each	Wrench, Crescent, length 8 in.
4	do	Wrenches, pipe, Stillson, length 10 in.

SECTION XII

TESTING STABILIZED MIXTURES AND CONCRETE

Paragraph
Stabilized mixtures 49
Concrete 50

49. Stabilized mixtures.—*a.* Stabilized mixtures are used in constructing subgrades, base courses, and surface courses. Table IV lists tests generally used for investigating aggregates and mixtures for planning and design, and control tests employed during construction. Unless otherwise explained, procedures are those given in section XI (app. III).

b. When it is necessary to blend two or more materials as in stabilizing clay subgrade with sand or in proportioning materials for a stabilized soil base, the procedure is usually one of preparing trial mixtures of representative samples of the available materials, followed by tests on the combinations to confirm their suitability. Proportions to be used in preparing trial mixes are guided by comparing characteristics of the individual materials. For example, if two gravels, one coarse and one fine, are to be combined to produce a graded gravel base material, an indication of the proper proportions for trial is obtained by studying the gradation curves of each material and estimating the percentage of each to give a combined material having the gradation desired. Similarly, if a sandy soil is to be added to a clay soil, an indication of desirable proportions may be obtained from the plasticity indexes of the two. Adding a sandy soil with low PI to a clay with high PI produces a combination with an intermediate PI. The decrease in PI is approximately proportionate to the amount of sandy soil added. Trial mixes are then tested for general suitability by appropriate procedures such as compaction and bearing ratio.

50. Concrete.—*a. Fine aggregate* (*sand*).—(1) Fine aggregate is judged by visual inspection for quality of individual particles. It is tested by sieve analysis for gradation and by washing for cleanliness. The washing test is made as follows: Fill a pint jar to a depth of 4 inches with sand and then fill almost full with water. Shake for several minutes. If there is more than ¼ inch of sediment on top of the sand after settling, the sand is unsuitable for important work. It may be made suitable by field washing to remove excess dirt.

(2) Sand is also tested for presence of injurious organic matter as follows: Fill a bottle half-full with sand to be tested. To it add a 3-percent solution of sodium hydroxide until volume of sand and water after shaking amounts to 1½ times original volume of sand alone.

Shake thoroughly and allow to stand for 24 hours. If liquid above the sand is colorless or yellow the sand is satisfactory as regards organic matter. If medium brown the sand is questionable and if dark brown the sand is unsuitable for important work. Field washing to remove dirt usually removes considerable organic matter also.

b. Coarse aggregate.—Coarse aggregate is judged by visual inspection and a sieve analysis. If it is dirty but otherwise satisfactory, field washing is required.

c. Proportions.—Proper proportions of water, cement, sand, and gravel are determined by trial mixes. The ratio of water to cement is held constant while proportions of fine and coarse aggregate are varied until a mix is obtained having required cement content per cubic yard and proper workability as judged by slump test. (See table LXI.)

d. Slump test.—A conical shell of 16-gage galvanized metal with a base 8 inches in diameter, a top 4 inches in diameter, and an altitude of 12 inches is filled to overflowing with concrete rodded into the shell in three separate layers, each layer receiving 25 strokes of a 5/8-inch bullet-pointed rod 24 inches in length. Excess is struck off and the mold is at once lifted, slowly and vertically. Amount of drop of the top of mass below original 12-inch height, measured in inches, is called slump of the mix. The slump test is a convenient method of controlling and checking uniformity of concrete production. Any major change of aggregate gradation, moisture content, or proportions during operations will be evidenced by a change in slump. When a change in slump occurs it is a signal to check and adjust operations.

TABLE XXXV

Description	Investigation tests for planning and design	Control tests during construction
Stabilized subgrade (par. 92).	Compaction (optimum moisture, maximum density) and bearing ratio tests on various combinations of subgrade soil and natural material to be admixed.	Grain-size distribution to check proportions. Field density to control compaction. Bearing ratio to confirm design.
Select borrow base (par. 91).	Liquid limit and plasticity index on fraction passing No. 40 sieve. Compaction (optimum moisture, and maximum density). Bearing ratio.	Field density to control compaction. Bearing ratio to confirm design.

TABLE XXXV—Continued

Description	Investigation tests for planning and design	Control tests during construction
Stabilized soil base and surface (pars. 92 and 121).	Combine various available materials by trial until a satisfactory mixture is obtained as shown by— Grain-size distribution test. Liquid limit and plasticity index on fraction passing No. 40 sieve. Compaction (optimum moisture and maximum density). Bearing ratio.	Grain-size distribution. Liquid limit and plasticity index on fraction passing No. 40 sieve. Field density to control compaction. Bearing ratio to confirm design.
Gravel, crushed gravel, and crushed rock base (par. 93).	Sieve analysis of gravel to determine need for filler. Combine gravel and filler if needed and test the combination by— Sieve analysis. Liquid limit and plasticity index on fraction passing No. 40 sieve. Compaction (optimum moisture maximum density). Bearing ratio.	Sieve analysis. Liquid limit and plasticity index on fraction passing No. 40 sieve. Field density to control compaction. Bearing ratio to confirm design.
Cement stabilized base (par. 94).	Sieve analysis of available aggregate and liquid limit and plasticity index on fraction passing No. 40 sieve. Prepare separate mixtures of cement and aggregate containing 8, 12, and 16 percent of cement by volume. Make laboratory compaction test for each mixture and determine optimum moisture and maximum density. Mold three compacted cylinders, 2 inches in diameter and 4 inches high, of each mixture. Exclude all pebbles larger than ½ inch when molding these cylinders.	Test aggregate before dry mixing for sieve analysis; also liquid limit and plasticity index on fraction passing No. 40 sieve. Measure windrows of aggregate to determine rate of spreading cement to give proper proportions. Check moisture content during wet mixing. Check field density during compaction. Mold, cure, and test several 2-inch by 4-inch cylinders from the wet mix in the field for confirmation. Procedure is the same as described in the investigation tests.

TABLE XXXV—Continued

Description	Investigation tests for planning and design	Control tests during construction
	Cylinders are filled in three layers, each layer well rammed as in the compaction test. Surface of first and second layers are roughened by scratching before adding second and third layers. Ends of cylinder must be *smooth and perpendicular to axis of cylinder*. Cure these cylinders at room temperature under continuously wet cloth or damp sand cover for 7 days. After 3 days of this 7-day period, one cylinder from each set of three is tested by the "pick test." (Hold specimen in one hand and lightly jab it with a dull ice pick from a distance of 2 or 3 inches). Repeat the test each day. Specimens that are hardening properly will show progressive resistance to the pick. At the end of 7 days make a compression test to failure of two of the cylinders from each mixture. The bearing ratio machine is used for compression tests. Record the maximum load registered on the dial before failure. Observe type of failure. A sudden shattering failure is favorable. A slow crumbling failure is an unfavorable indication. An acceptable soil-cement mixture should develop a crushing strength of 400 pounds per square inch at 7 days.	

TABLE XXXV—Continued

Description	Investigation tests for planning and design	Control tests during construction
Cement stabilized base—(Con.).	(Total load on a 2-inch cylinder, 1,250 pounds.) The third cylinder of each mixture is *immersed in water.* After 3 hours it is given a severe "pick test." Penetration of the pick, under considerable force, should not exceed ⅛ to ¼ inch. The cylinder is again immersed in water for several days and observed daily for any tendency to soften or crumble.	
Bituminous mixtures (pars. 95 and 122).	Sieve analysis of available aggregates to determine acceptability or need for blending or combination of additional natural material. After proper grading is achieved, the combined aggregate is tested for liquid limit and plasticity index of fraction passing No. 40 sieve. Compute bitumen proportion for combined aggregate as per paragraph 118. Select appropriate or available bitumen (asphalt or tar) from tables XXXVII and XXXVIII. Prepare mixtures using selected or available bitumen in proportion needed. Compact the mixture in a cylinder and observe density and general character. Allow cylinder to cure in air for further observation. NOTE.—This type of mixture does not develop rigidity as does soil cement.	Sieve analysis of aggregate in windrows after dry-mixing. Compute required proportion of bitumen as per paragraph 118. Measure windrows, table LVI. Compute quantity and length of spread of bitumen as per paragraph 120*b*.

Section XIII

SUBSURFACE DRAINAGE FOR PAVEMENTS

Paragraph
General ---------- 51
Uses ---------- 52
Subdrain systems ---------- 53
Filter material ---------- 54
Backfill material ---------- 55

51. General.—At most airdromes stability of subgrade and base course soils under pavements cannot be increased by providing a subdrainage system. For this reason, base courses should be constructed that will provide sufficient stability for the pavement surface, regardless of subgrade moisture conditions. All soils, except clean sands and gravels, under a wide pavement will remain practically saturated due to capillarity or condensation, or both. Shallow drains under pavement are not desirable unless absolutely necessary because bearing under pavement is nonuniform and settlement often occurs in the region of the drains. Clean sands and gravels, which are pervious do not require subdrains to insure stable conditions. Such soils are not detrimentally affected by frost action, and have high bearing capacity, even though saturated. However, thin strata and base courses of pervious sands should be drained if underlain by material that will be affected by frost action.

52. Uses.—Although satisfactory subdrainage of soils underlying pavements at most sites is impractical, subdrainage may be considered if the following conditions occur:

a. The free ground-water table is near the base of the pavement.

b. Shallow sand and gravel strata, or base courses, overlie silty or clayey soils, subject to frost action.

c. The water supply to potential frost-action soils may be satisfactorily intercepted.

53. Subdrain systems.—If it is desired to drain the subgrade or base course under an airdrome pavement, experience has shown that in most cases a subdrain system along edges of the pavement will be the most satisfactory. The subdrain should consist of a perforated or open bell-and-spigot joint pipe placed at least 5 feet below the pavement surface except where used solely for base drainage. The trench in which pipe is placed should be backfilled with suitable filter material, except the top 6 or 12 inches which should be filled with impervious material. The filter material should join the base course layer. Base course material outside of the pavement wearing surface should underlie an impervious layer of soil which will prevent surface rainwater from entering the subdrain system. The subdrain and surface drain systems should not be connected unless they are designed so that water in subdrain pipes will not be under pressure during periods of major storms. If water is forced into the subdrains from the surface drain system, pervious strata of subgrade and base course material will become saturated and therefore defeat the purpose of the subdrain system.

54. Filter material.—Many failures of subdrainage systems have been due to movement of material from the pipe-trench walls into the filter. This has resulted in pavement collapse along the edges, or complete clogging of the drain. Thus is emphasized importance of carefully selecting filter material. Filter material should be as pervious as possible and still have a gradation which will prevent movement of natural soils. The gradation of filter material required is governed by the gradation of the foundation (subgrade) material. It has been found by tests that gradation of the filter material should meet the following requirements:

$$\frac{15\%\ \text{size—filter}}{85\%\ \text{size—uniform foundation}}\quad \text{not greater than } 4$$

$$\frac{15\%\ \text{size—filter}}{85\%\ \text{size—well-graded foundation}}\quad \text{not greater than } 5$$

$$\frac{15\%\ \text{size—filter}}{15\%\ \text{size—uniform foundation}}\quad \text{not greater than } 5$$

$$\frac{15\%\ \text{size—filter}}{15\%\ \text{size—well-graded foundation}}\quad \text{not greater than } 25$$

The percent size is defined as grain size, corresponding to the percent finer by weight on the sieve analysis curve. All filter materials should be thoroughly compacted to produce stable material and to insure against future settlement of the surface.

55. Backfill material.—For some drainpipes, where openings are large, an additional layer of coarse material will be required adjacent to the pipe to prevent movement of backfill or filter material into the pipe. Where the natural material is definitely cohesive, a greater difference between backfill and natural material can be allowed. The most unstable materials are fine sands and coarse silts; therefore special attention should be given to selection of backfill materials wherever these types of soils are encountered. Backfill material should be compacted to form a uniformly dense mass in order that maximum stability will be obtained.

APPENDIX IV

TABLES AND INFORMATION USEFUL IN BITUMINOUS CONSTRUCTION

TABLE XXXVI.—*Bituminous materials*

Material	Source	Form	Grade designation—temperature °F. applied	Remarks
Cut-back asphalts (RC and MC).	Product of refining crude petroleum oils containing asphalt.	Liquids—asphalt residues fluxed with more volatile petroleum distillates.	*Rapid curing* RC–0 50–120 –1 50–120 –2 100–175 –3 150–200 –4 175–250 –5 175–250	Naptha (highly volatile), evaporating quickly, leaving asphalt cement binder, permits early use of surface.
			Medium curing MC–0 50–120 –1 80–125 –2 150–200 –3 175–250 –4 175–250 –5 200–275	Kerosene (less volatile) does not evaprate so quickly and cures more slowly than RC types.
Asphaltic road oils (SC).	Product of refining crude petroleum oils containing asphalt.	Liquids—low volatile oils left or blended with asphalt residues near end of refining process.	*Slow curing* SC–0 50–120 –1 50–120 –2 120–180 –3 175–250 –4 200–275 –5 200–275 –6 250–300	
Asphaltic cements (AC) or paving asphalts.	Product of refining crude petroleum oils containing asphalt.	Semiliquids or solids.	*Penetration* 40– 50 50– 60 60– 70 70– 85 85–100 100–120 120–150 150–200 *Temp.* 250 to 350	Penetrations 40 to 100 used for crack and joint fillers.
Powdered asphalt (PA).	Product of refining crude petroleum oils containing asphalt.	Hard and solid asphalts ground to powder.	----------------	Used with SC oils to produce extra tough road surfaces.

TABLE XXXVI.—*Bituminous material*—Continued

Material	Source	Form	Grade designation—temperature °F. applied	Remarks
Asphalt emulsions (AE).	Asphalt cements in water with an emulsifying agent.	Liquids	*Rapid, medium, and slow setting*	Freezing destroys emulsion.
			RS-1 60-120	Penetration and surface treatments.
			MS-1 60-120	Mixed in place and plant mixes with coarse aggregate.
			-2 60-120	
			-3 60-120	
			SS-1 50-120	Mixed in place and plant mixes with fine aggregate.
			-2 50-120	
Road tar (RT) priming oils.	All road tars are products of coking bituminous coal.	Liquids	RT-1 60-125	Waterproofs surfaces preparatory to placing other bituminous surfaces.
			-2 60-125	
			-3 80-150	
Cold tars (TC)	All road tars are products of coking bituminous coal.	Liquids	RT-4 80-150	Mixed in place and patching.
			-5 80-150	
			-6 80-150	
			-7 150-225	
Hot tars (TH)	All road tars are products of coking bituminous coal.	Nonliquids	RT-8 150-225	Patching and seal coats.
			-9 150-225	Plant mix and sea coats.
			-10 175-250	
			-11 175-250	
			-12 175-250	Penetration macadam
Cut-back tars (RTCB).	Tars combined with volatile distillates from coal or water-gas tar.	Liquids	RTCB-5 60-120	Patching mixtures.
			-6 60-120	
Rock asphalt	Natural combinations of asphalt with sand or stone.	Solids		Mined and used locally where found.

TABLE XXXVII.—*Typical uses of asphaltic materials*

Purpose or use	Grade or designation				
	RC (Rapid curing)	MC (Medium curing)	SC (Slow curing)	AC (Asphalt cement, with penetration of—)[1]	AE (Emulsified asphalt)
Dust palliative		MC-0, -1, -2	SC-0, -1, -2		
Prime coats:					
Tightly bonded surfaces		MC-0	SC-1		
Loosely bonded fine grained surfaces		MC-1	SC-2		
Loosely bonded coarse grained surfaces		MC-2	SC-3		
Surface treatments and seal coats:					
With or without light sand cover	RC-0				RS-1
Coarse sand cover	RC-1	MC-2, -3			RS-1
Clean ¼-inch aggregate cover	RC-2				RS-1
Clean ½-inch aggregate cover	RC-3			150-200	
Clean ⅝-inch aggregate cover	RC-4			150-200	
Clean ¾-inch aggregate cover	RC-5	MC-4, -5		150-200	
Graded gravel aggregate cover		MC-2, -3	SC-3		
Gravel mulch		MC-2	SC-2		
Mixed in place:					
Open graded aggregate:					
Sand	RC-1, -2	MC-3			
Maximum diameter 1 inch, high percentage passing 10 mesh		MC-3, -4			
Macadam aggregate	RC-2, -3				
Dense graded aggregate:					
High percentage passing 200 mesh		MC-2	SC-2		
Maximum diameter 1 inch, high percentage passing 200 mesh		MC-2, -3	SC-2, -3		
Cold patch:					
Open graded aggregate	RC-2	MC-3	SC-3		MS-3
Dense graded aggregate		MC-2	SC-2		
Cold laid plant mix:					
Open graded aggregate:					
Sand	RC-2, -3				MS-2
Maximum diameter 1 inch, high percentage passing 10 mesh	RC-3		SC-3		MS-3
Macadam aggregate	RC-4, -5				
Dense graded aggregate:					
High percentage passing 200 mesh		MC-3, -4	SC-3, -4		SS-2
Maximum diameter 1 inch, median percentage passing 200 mesh		MC-4	SC-4		SS-1
Aggregate precoating followed with asphalt		MC-0	SC-1		
Hot laid plant mix	RC-4, -5	MC-4, -5	SC-5, -6	150-200	
Penetration macadam:					
Cold weather	RC-5		SC-6		
Hot weather				100-200	RS-1
Asphaltic concrete				40-150	

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[1] Penetrations of 100, 120, 150, and 200 show increasing softness or fluidity. Penetrations of 85, 70, 60, 50, 40, etc., show increasing hardness or solidity. Road oil SC-6 (with high viscosity) and the softest paving asphalts both have penetrations of about 200.

Table XXXVIII.—*Standard grades of road tar—their uses and application temperature*

Grade	Use	Application temperature (° F.)
RT-1	Soil stabilization and dust layer	60-125
RT-2	Prime coat for dense tight surfaces and for ordinary surfaces in cool weather and soil stabilization.	60-125
RT-3	Prime coat for ordinary surfaces in hot weather, mastic cushion under brick pavement in cool weather, surface treatments, and soil stabilization.	80-150
RT-4	Prime coat for open surfaces in hot weather, surface treatments, and soil stabilization.	80-150
RT-5	Surface treatment, mulch treatment and dense graded aggregate type of road mix in cool weather, mastic cushion in warm weather, and soil stabilization.	80-150
RT-6	Surface treatment, drag leveling course in cool weather, coarse aggregate type road mix in cool weather, mulch treatment and road mix, graded aggregate type in warm weather, and soil stabilization.	
RT-7	Surface treatment, drag leveling course in warm weather, coarse aggregate type road mix in cool weather, sand mix in cool weather, and cold premix in cool weather.	150-225
RT-8	Surface treatment, drag leveling course in warm weather, coarse aggregate type road mix in warm weather, sand mix in warm weather, and cold premix in cool weather.	150-225
RT-9	Surface treatment, coarse aggregate type road mix in warm weather, sand mix in warm weather, and cold premix in warm weather.	150-225
RT-10	Surface treatment, cold premix in warm weather, and hot patch.	175-250
RT-11	Hot premix, penetration macadam in cool weather, hot patch, and crack filler.	175-250
RT-12	Hot premix, penetration macadam in warm weather, hot patch, and crack filler.	175-250
RTCB-5	Cold patch in cool weather, road mix and premix when desired to use a cold application, and quick setting binder.	60-120
RTCB-6	Cold patch in warm weather, road mix and premix when desired to use a cold application, and quick setting binder.	60-120

TABLE XXXIX.—*Average weights and volumes of bituminous materials*

	Gallons per ton at 60° F.	*Barrels per ton at 60° F.	Pounds per gallon at 60° F.	Pounds per barrel* at 60° F.
SC, MC, AND RC ASPHALTS				
Grade:				
0	257	6. 11	7. 79	327
1	251	5. 98	7. 97	335
2	248	5. 90	8. 07	339
3	245	5. 84	8. 16	343
4	243	5. 78	8. 23	346
5	241	5. 74	8. 30	349
6 (SC only)	239	5. 70	8. 36	351
ASPHALT CEMENTS				
Penetration:				
40 to 100	235	5. 60	8. 51	358
100 to 200	237	5. 64	8. 44	354
EMULSIFIED ASPHALTS				
All grades	240	5. 72	8. 33	350
TARS				
RT–1	211	5. 01	9. 50	399
RT–2	209	4. 97	9. 56	402
RT–3	208	4. 94	9. 64	404
RT–4	206	4. 90	9. 71	408
RT–5	205	4. 87	9. 78	411
RT–6	203	4. 84	9. 85	414
RT–7	201	4. 80	9. 93	417
RT–8	200	4. 76	10. 00	420
RT–9	199	4. 73	10. 07	423
RT–10	197	4. 70	10. 15	426
RT–11	195	4. 66	10. 22	430
RT–12	194	4. 63	10. 30	432
RTCB–5	205	4. 87	9. 78	411
RTCB–6	203	4. 84	9. 85	414

*A barrel is 42 U. S. gallons. This is a common unit of measure in United States. Steel drums in which bituminous products are shipped usually contain 55 U. S. gallons.

TABLE XL.—*Distribution table for bituminous materials*

(1.0 gallon spread per square yard of finished surface)

Gallons of bitumen	Width of spread in feet												Gallons of bitumen
	1	2	3	4	5	6	7	8	9	10	11	12	
	Length of spread in linear feet												
5	45	23	15	11	9	8	6	6	5	5	4	4	5
10	90	45	30	23	18	15	13	11	10	9	8	7	10
15	135	68	45	34	27	23	19	17	15	14	12	11	15
20	180	90	60	45	36	30	26	22	20	18	16	15	20
25	225	113	75	56	45	38	32	28	25	23	21	19	25
30	270	135	90	68	54	45	38	34	30	27	25	23	30
35	315	158	105	79	63	53	45	39	35	31	29	26	35
40	360	180	120	90	72	60	51	45	40	36	33	30	40
45	405	203	135	101	81	68	58	50	45	40	37	34	45
50	450	225	150	113	90	75	64	56	50	45	41	38	50
55	495	248	165	124	99	83	70	62	55	50	45	41	55
60	540	270	180	135	108	90	77	67	60	54	49	45	60
65	585	293	195	146	117	98	83	73	65	59	53	49	65
70	630	315	210	158	126	105	90	79	70	63	57	53	70
75	675	338	225	169	135	113	96	84	75	68	62	56	75
80	720	360	240	180	144	120	102	90	80	72	66	60	80
85	765	383	255	191	153	127	109	95	85	77	70	64	85
90	810	405	270	203	162	135	115	101	90	81	74	68	90
95	855	428	285	214	171	143	122	107	95	85	78	71	95
100	900	450	300	225	180	150	128	112	100	90	82	75	100
200	1,800	900	600	450	360	300	256	225	200	180	164	150	200
300	2,700	1,350	900	675	540	450	386	338	300	270	246	225	300
400	3,600	1,800	1,200	900	720	600	514	450	400	360	327	300	400
500	4,500	2,250	1,500	1,125	900	750	643	563	500	450	409	375	500
600	5,400	2,700	1,800	1,350	1,080	900	772	675	600	540	491	450	600
700	6,300	3,150	2,100	1,575	1,260	1,050	900	788	700	630	573	525	700
800	7,200	3,600	2,400	1,800	1,440	1,200	1,029	900	800	720	655	600	800
900	8,100	4,050	2,700	2,025	1,620	1,350	1,157	1,013	900	810	736	675	900
1,000	9,000	4,500	3,000	2,250	1,800	1,500	1,286	1,125	1,000	900	818	750	1,000
1,100	9,900	4,950	3,300	2,475	1,980	1,650	1,415	1,237	1,100	990	900	825	1,100
1,200	10,800	5,400	3,600	2,700	2,160	1,800	1,543	1,350	1,200	1,080	982	900	1,200
1,300	11,700	5,850	3,900	2,925	2,340	1,950	1,671	1,462	1,300	1,170	1,064	975	1,300
1,400	12,600	6,300	4,200	3,150	2,520	2,100	1,800	1,575	1,400	1,260	1,146	1,050	1,400
1,500	13,500	6,750	4,500	3,375	2,700	2,250	1,929	1,688	1,500	1,350	1,228	1,125	1,500

TABLE XLI.—*Gallons of bitumen required per mile at various rates of application per square yard*

Width (feet)	⅛ gal.	⅕ gal.	¼ gal.	⅓ gal.	⁴⁄₁₀ gal.	½ gal.	¾ gal.	1 gal.
18	1, 320	2, 112	2, 640	3, 520	4, 224	5, 280	7, 920	10, 560
17	1, 247	1, 995	2, 493	3, 324	3, 989	4, 987	7, 479	9, 974
16	1, 173	1, 877	2, 347	3, 129	3, 754	4, 693	7, 041	9, 387
15	1, 100	1, 760	2, 200	2, 933	3, 520	4, 400	6, 600	8, 800
14	1, 027	1, 643	2, 053	2, 738	3, 285	4, 107	6, 159	8, 213
13	953	1, 525	1, 907	2, 542	3, 050	3, 813	5, 721	7, 627
12	880	1, 408	1, 760	2, 346	2, 816	3, 520	5, 280	7, 040
11	807	1, 291	1, 613	2, 151	2, 581	3, 227	4, 839	6, 454
10	734	1, 173	1, 467	1, 955	2, 346	2, 933	4, 401	5, 867
9	660	1, 056	1, 320	1, 760	2, 112	2, 640	3, 960	5, 280

TABLE XLII.—*Method for determining weight of bitumen per gallon at applied temperature*

Obtain from engineer or determine—

(1)—Specific gravity of the bitumen at 60° F.

(2)—Classify specific gravity:

If specific gravity is greater than 0.966 use Table "A".
If specific gravity is less than 0.966 use Table "B".

(3)—Applied temperature of bitumen.

Calculate—

(4)—Select from proper table the multiplier opposite the applied temperature.

(5)—Multiply (4) × (1) for specific gravity of bitumen at applied temperature.

(6)—In table "C" find lbs. per gal. bitumen opposite specific gravity of bitumen at applied temperature.

Example—

(1)—Specific gravity of bitumen at 60° F. =1.011.

(2)—Classify specific gravity of bitumen=Table "A".

(3)—Applied temperature of bitumen=300° F.

Calculate—

(4)—Multiplier at 300° F.=0.9201.

(5)—0.9201×1.011 specific gravity=0.930 specific gravity at applied temperature.

(6)—In Table "C" opposite specific gravity 0.930=7.745 lbs. per gal. at applied temperature.

Note—

Weight of water per gal. at 60° F.=8.328 lbs.
Specific gravity of water at 60° F.=1,000.

TABLE NO. A.—*Specific gravity at 60° F., above 0.966*

t=observed temperature ° F.
M=multiplier to reduce volume to 60° F.

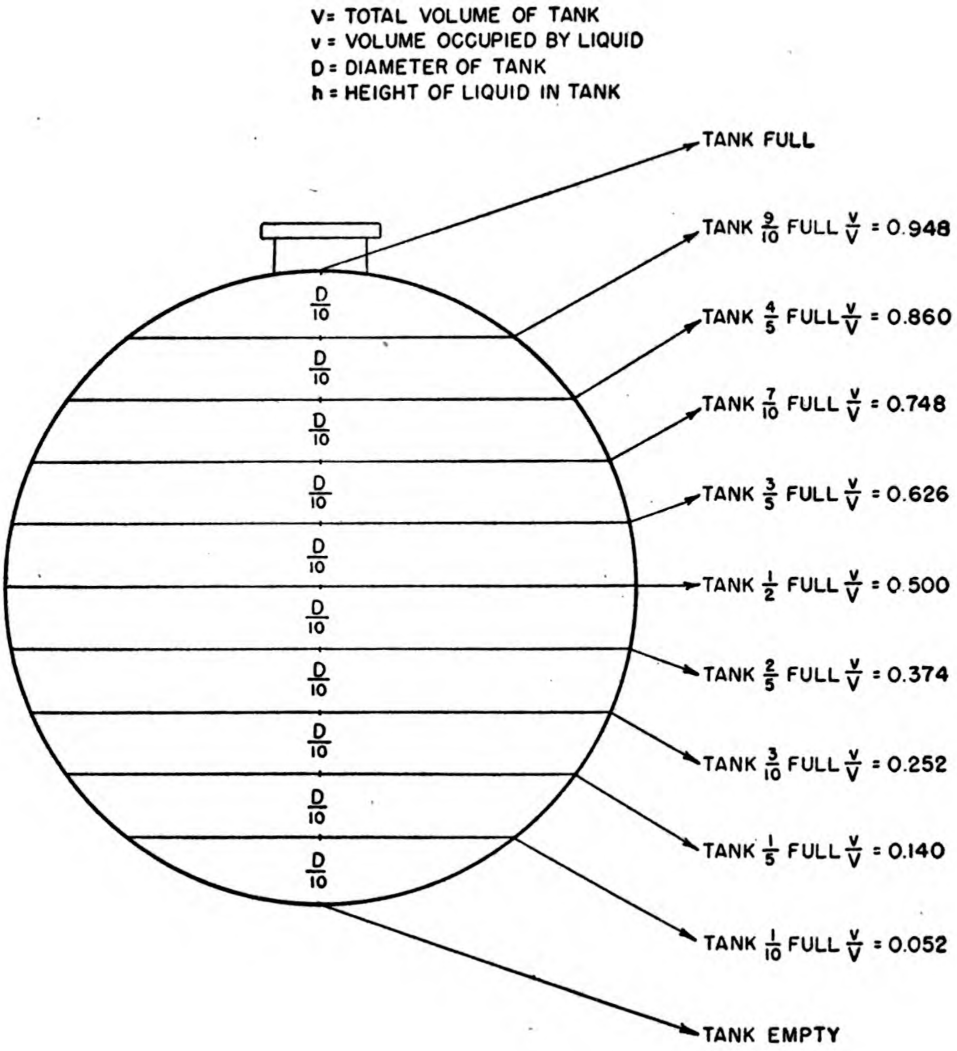
t	M	t	M	t	M	t	M
60	1.0000	135	0.9741	210	0.9490	285	0.9248
65	.9982	140	.9724	215	.9474	290	.9233
70	.9965	145	.9707	220	.9458	295	.9217
75	.9948	150	.9691	225	.9441	300	.9201
80	.9931	155	.9674	230	.9425	305	.9185
85	.9914	160	.9657	235	.9409	310	.9169
90	.9896	165	.9640	240	.9392	315	.9154
95	.9879	170	.9635	245	.9376	320	.9138
100	.9862	175	.9606	250	.9360	325	.9123
105	.9844	180	.9590	255	.9344	330	.9107
110	.9827	185	.9573	260	.9328	335	.9092
115	.9809	190	.9556	265	.9312	340	.9076
120	.9702	195	.9539	270	.9296	345	.9061
125	.9775	200	.9523	275	.9280	350	.9045
130	.9758	205	.9507	280	.9264	355	.9030

TABLE NO. B.—*Specific gravity at 60° F., 0.850 to 0.966*

t	M	t	M	t	M	t	M
60	1.0000	120	0.9763	180	0.9532	240	0.9307
65	.9980	125	.9744	185	.9513	245	.9289
70	.9960	130	.9724	190	.9494	250	.9270
75	.9940	135	.9705	195	.9476	255	.9252
80	.9921	140	.9686	200	.9457	260	.9234
85	.9901	145	.9667	205	.9438	265	.9215
90	.9881	150	.9647	210	.9419	270	.9197
95	.9861	155	.9628	215	.9401	275	.9179
100	.9841	160	.9608	220	.9382	280	.9160
105	.9822	165	.9590	225	.9363	285	.9145
110	.9803	170	.9570	230	.9345	290	.9124
115	.9783	175	.9551	235	.9326	295	.9106

TABLE NO. C.—*Weight and volume relations asphaltic materials*

Sp. gr.	*Lbs. per gal.*	*Sp. gr.*	*Lbs. per gal.*	*Sp. gr.*	*Lbs. per gal.*	*Sp. gr.*	*Lbs. per gal.*
0.880	7.329	0.930	7.745	0.980	8.162	1.030	8.578
0.885	7.370	0.935	7.786	0.985	8.203	1.035	8.620
0.890	7.412	0.940	7.828	0.990	8.245	1.040	8.662
0.895	7.453	0.945	7.870	0.995	8.287	1.045	8.704
0.900	7.495	0.950	7.911	1.000	8.328	1.050	8.745
0.905	7.536	0.955	7.953	1.005	8.370	1.055	8.787
0.910	7.578	0.960	7.995	1.010	8.412	1.100	9.161
0.915	7.619	0.965	8.036	1.015	8.453	1.200	9.994
0.920	7.662	0.970	8.078	1.020	8.495	1.300	10.826
0.925	7.703	0.975	8.120	1.025	8.537	1 400	11.659


V= TOTAL VOLUME OF TANK
v = VOLUME OCCUPIED BY LIQUID
D = DIAMETER OF TANK
h = HEIGHT OF LIQUID IN TANK
TANK FULL
TANK $\frac{9}{10}$ FULL $\frac{v}{V}$ = 0.948
TANK $\frac{4}{5}$ FULL $\frac{v}{V}$ = 0.860
TANK $\frac{7}{10}$ FULL $\frac{v}{V}$ = 0.748
TANK $\frac{3}{5}$ FULL $\frac{v}{V}$ = 0.626
TANK $\frac{1}{2}$ FULL $\frac{v}{V}$ = 0.500
TANK $\frac{2}{5}$ FULL $\frac{v}{V}$ = 0.374
TANK $\frac{3}{10}$ FULL $\frac{v}{V}$ = 0.252
TANK $\frac{1}{5}$ FULL $\frac{v}{V}$ = 0.140
TANK $\frac{1}{10}$ FULL $\frac{v}{V}$ = 0.052
TANK EMPTY
$\frac{D}{10}$
$\frac{D}{10}$
$\frac{D}{10}$
$\frac{D}{10}$
$\frac{D}{10}$
$\frac{D}{10}$
$\frac{D}{10}$
$\frac{D}{10}$
$\frac{D}{10}$
$\frac{D}{10}$

TANK DIVIDED INTO 10 PARTS OF EQUAL HEIGHT. (CASE IN WHICH MEASUREMENT IS TAKEN WITH AN ORDINARY FOOT RULE.)

FIGURE 203.—Content of horizontal cylindrical tanks.

TABLE XLIII.—*Contents of cylindrical and elliptical tanks (horizontal)*

(Full capacity in gallons = [.7854 x dia.^{2} (inches) x length (inches)] ÷ 231)

Percent of depth		Percent of capacity		Percent of depth		Percent of capacity	
1—filled	2—unfilled	1a—filled	2a—unfilled	1—filled	2—unfilled	1a—filled	2a—unfilled
1	**99**	0. 20	**99. 80**	26	**74**	20. 73	**79. 27**
2	**98**	0. 50	**99. 50**	27	**73**	21. 86	**78. 14**
3	**97**	0. 90	**99. 10**	28	**72**	23. 00	**77. 00**
4	**96**	1. 34	**98. 66**	29	**71**	24. 07	**75. 93**
5	**95**	1. 87	**98. 13**	30	**70**	25. 31	**74. 69**
6	**94**	2. 45	**97. 55**	31	**69**	26. 48	**73. 52**
7	**93**	3. 07	**96. 93**	32	**68**	27. 66	**72. 34**
8	**92**	3. 74	**96. 26**	33	**67**	28. 84	**71. 16**
9	**91**	4. 45	**95. 55**	34	**66**	30. 03	**69. 97**
10	**90**	5. 20	**94. 80**	35	**65**	31. 19	**68. 81**
11	**89**	5. 98	**94. 02**	36	**64**	32. 44	**67. 56**
12	**88**	6. 80	**93. 20**	37	**63**	33. 66	**66. 34**
13	**87**	7. 64	**92. 36**	38	**62**	34. 90	**65. 10**
14	**86**	8. 50	**91. 50**	39	**61**	36. 14	**63. 86**
15	**85**	9. 40	**90. 60**	40	**60**	37. 39	**62. 61**
16	**84**	10. 32	**89. 68**	41	**59**	38. 64	**61. 36**
17	**83**	11. 27	**88. 73**	42	**58**	39. 89	**60. 11**
18	**82**	12. 24	**87. 76**	43	**57**	41. 14	**58. 86**
19	**81**	13. 23	**86. 77**	44	**56**	42. 40	**57. 60**
20	**80**	14. 23	**85. 77**	45	**55**	43. 66	**56. 34**
21	**79**	15. 26	**84. 74**	46	**54**	44. 92	**55. 08**
22	**78**	16. 32	**83. 68**	47	**53**	46. 19	**53. 81**
23	**77**	17. 40	**82. 60**	48	**52**	47. 45	**52. 55**
24	**76**	18. 50	**81. 50**	49	**51**	48. 73	**51. 27**
25	**75**	19. 61	**80. 39**	50	**50**	50. 00	**50. 00**

Columns No. 1 and No. 1a should be used together to ascertain percentage of capacity filled when less than 50%.

Columns No. 2 and No. 2a should be used together to ascertain percentage of capacity filled when greater than 50%.

TABLE XLIV.—*Temperature of saturated steam at various gage pressures*

Gage pressure (lbs. per sq. in.)	Temperature of saturated steam (°F.)	Highest temperature a liquid can be heated in a vessel with heating equipment 85% efficient
50	297	253
55	302	257
60	307	261
65	312	265
70	316	269
75	320	272
80	324	275
85	327	278
90	331	281
95	334	284
100	338	287
105	341	290
110	344	292
115	347	295
120	350	298
125	353	300
130	355	302
135	358	304
140	361	307
145	363	309
150	366	311

APPENDIX V

TABLES AND CHARTS USEFUL IN ESTIMATING, CONSTRUCTION, AND LABORATORY WORK

TABLE XLV.—*Linear feet covered by one ton of aggregate (at various rates of application)*

Pounds per square yard	Width of runway strip							
	6	8	9	12	16	18	20	24
3	1,000	750	667	500	375	333	300	250
5	600	450	400	300	225	200	180	150
7	428	321	285	214	161	143	129	107
10	300	225	200	150	113	100	90	75
12	250	188	167	125	94	83	75	63
15	200	150	133	100	75	67	60	50
20	150	113	100	75	56	50	45	38
25	120	90	80	60	45	40	36	30
30	100	75	67	50	38	33	30	25
35	86	64	57	43	32	29	26	21
40	75	56	50	38	28	25	23	19
45	67	50	44	33	25	22	20	17
50	60	45	40	30	23	20	18	15
55	55	41	36	27	20	18	16	14
60	50	38	33	25	19	17	15	13
65	46	35	31	23	17	15	14	12
70	43	32	29	21	16	14	13	11
75	40	30	27	20	15	13	12	10

TABLE XLVI.—*Pounds of aggregate per square yard required to make various thicknesses of compacted layer*

One cu. yd. of dry aggregate in pounds (loose measure)	Thickness of pavement							
	½ inch	¾ inch	1 inch	1½ inches	2 inches	2½ inches	3 inches	3½ inches
2,100	37	56	74	112	149	186	223	260
2,200	38	58	77	115	154	192	231	269
2,300	40	60	80	119	159	199	239	278
2,400	41	61	82	123	164	205	246	287
2,500	42	63	84	127	169	211	253	295
2,600	43	65	87	130	173	217	260	303
2,700	44	67	89	133	178	222	267	311
2,800	45	68	91	136	182	227	273	318
2,900	47	70	93	140	186	233	279	326
3,000	47	71	95	142	190	237	285	332
3,100	48	73	97	145	194	242	291	339
3,200	49	74	99	148	197	247	296	345
3,300	50	75	100	151	201	251	301	351
3,400	51	77	103	154	206	257	309	360

Weight per cubic yard compacted is approximately 1.25 times weight per cubic yard loose.
See par. 120 for method of determining dry-loose unit weight of aggregate.

TABLE XLVII.—*Cubic yard weights in pounds in ton weight equivalents*

Weight of aggregates in pounds per cubic yard	Equivalent weight in tons	Fractional number of cubic yards per ton
2,100	1. 050	0. 952
2,150	1. 075	0. 930
2,200	1. 100	0. 909
2,250	1. 125	0. 888
2,300	1. 150	0. 869
2,350	1. 175	0. 851
2,400	1. 200	0. 833
2,450	1. 225	0. 816
2,500	1. 250	0. 800
2,550	1. 275	0. 784
2,600	1. 300	0. 769
2,650	1. 325	0. 754
2,700	1. 350	0. 740
2,750	1. 375	0. 727
2,800	1. 400	0. 714
2,850	1. 425	0. 701
2,900	1. 450	0. 689
2,950	1. 475	0. 677
3,000	1. 500	0. 666
3,050	1. 525	0. 655
3,100	1. 550	0. 645
3,150	1. 575	0. 635
3,200	1. 600	0. 625
3,250	1. 625	0. 615
3,300	1. 650	0. 606

Table XLVIII.—*Broken stone*

(Lbs. per cu. yd.)

Kind	Specific gravity	Spread loose (45% voids)	Compacted (30% voids)
Trap	2. 8	2, 590	3, 300
	2. 9	2, 680	3, 420
	3. 0	2, 770	3, 540
	3. 1	2, 870	3, 650
Granite	2. 6	2, 400	3, 060
	2. 7	2, 500	3, 180
	2. 8	2, 590	3, 300
Limestone	2. 6	2, 400	3, 060
	2. 7	2, 500	3, 180
	2. 8	2, 590	3, 300
Sandstone	2. 4	2, 220	2, 830
	2. 5	2, 310	2, 940
	2. 6	2, 400	3, 060
	2. 7	2, 500	3, 180

Table XLIX.—*Cubic yards per mile*

Width (feet)	Thickness (inches)	Cubic yards	
		100 feet	1 mile
9	2	5. 55	293
	2½	6. 95	367
	3	8. 33	440
	4	11. 10	587
	6	16. 66	880
	7	19. 43	1, 027
	8	22. 20	1, 173
	9	25. 00	1, 320
15	2	9. 20	489
	2½	11. 57	611
	3	13. 89	733
	4	18. 42	978
	6	27. 78	1, 467
	7	32. 30	1, 711
	8	37. 04	1, 956
	9	41. 70	2, 200
16	2	9. 88	522
	2½	12. 35	652
	3	14. 82	782
	4	19. 76	1, 043
	6	29. 64	1, 564
	7	34. 58	1, 825
	8	39. 32	2, 086
	9	44. 46	2, 347
20	2	12. 35	652
	2½	15. 44	815
	3	18. 50	978
	4	24. 70	1, 304
	6	37. 00	1, 956
	7	43. 20	2, 281
	8	49. 40	2, 607
	9	55. 54	2, 933

TABLE L.—*Square yards per 100 feet and per mile for different width of surface*

	Number of square yards			Number of square yards	
	Per 100 feet	Per mile		Per 100 feet	Per mile
Width in feet:			Width in feet:		
8	88.889	4,693	26	288.889	15,253
10	111.111	5,867	28	311.111	16,427
12	133.333	7,040	30	333.333	17,600
14	155.556	8,213	32	355.556	18,773
15	166.667	8,800	34	377.778	19,947
16	177.778	9,387	36	400.000	21,120
18	200.000	10,560	38	422.222	22,293
20	222.222	11,734	40	444.444	23,466
22	244.444	12,907	42	466.667	24,640
24	266.667	14,080	44	488.889	25,813

TABLE LI.—*Miles and tenths reduced to feet.*

Miles	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	0.1
Feet	5,280	5,808	6,336	6,864	7,392	7,920	8,448	8,976	9,504	10,032	528
Miles	2.0	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9	0.2
Feet	10,560	11,088	11,616	12,144	12,672	13,200	13,728	14,256	14,784	15,312	1,056
Miles	3.0	3.1	3.2	3.3	3.4	3.5	3.6	3.7	3.8	3.9	0.3
Feet	15,840	16,368	16,896	17,424	17,952	18,480	19,008	19,536	20,064	20,592	1,584
Miles	4.0	4.1	4.2	4.3	4.4	4.5	4.6	4.7	4.8	4.9	0.4
Feet	21,120	21,648	22,176	22,704	23,232	23,760	24,288	24,816	25,344	25,872	2,112
Miles	5.0	5.1	5.2	5.3	5.4	5.5	5.6	5.7	5.8	5.9	0.5
Feet	26,400	26,928	27,456	27,984	28,512	29,040	29,568	30,096	30,624	31,152	2,644
Miles	6.0	6.1	6.2	6.3	6.4	6.5	6.6	6.7	6.8	6.9	0.6
Feet	31,680	32,208	32,736	33,264	33,792	34,320	34,848	35,376	35,904	36,432	3,168
Miles	7.0	7.1	7.2	7.3	7.4	7.5	7.6	7.7	7.8	7.9	0.7
Feet	36,960	37,488	38,016	38,544	39,072	39,600	40,128	40,656	41,184	41,712	3,696
Miles	8.0	8.1	8.2	8.3	8.4	8.5	8.6	8.7	8.8	8.9	0.8
Feet	42,240	42,768	43,296	43,824	44,352	44,880	45,408	45,936	46,464	46,992	4,224
Miles	9.0	9.1	9.2	9.3	9.4	9.5	9.6	9.7	9.8	9.9	0.9
Feet	47,520	48,048	48,576	49,104	49,632	50,160	50,688	51,216	51,744	52,272	4,752

TABLE LII.—*Temperatures*
(Fahrenheit and Centigrade)

C.	F.	C.	F.	C.	F.	C.	F.
−29	−20. 2	15	59. 0	59	138. 2	169	336. 2
−28	−18. 4	16	60. 8	60	140. 0	170	338. 0
−27	−16. 6	17	62. 6	61	141. 8	171	339. 8
−26	−14. 8	18	64. 4	62	143. 6	172	341. 6
−25	−13. 0	19	66. 2	63	145. 4	173	343. 4
−24	−11. 2	20	68. 0	64	147. 2	174	345. 2
−23	−9. 4	21	69. 8	65	149. 0	175	347. 0
−22	−7. 6	22	71. 6	66	150. 8	176	348. 8
−21	−5. 8	23	73. 4	100	212. 0	177	350. 6
−20	−4. 0	24	75. 2	121	249. 8	178	352. 4
−19	−2. 2	25	77. 0	135	275. 0	179	354. 2
−18	−0. 4	26	78. 8	136	276. 8	180	356. 0
−17	+1. 4	27	80. 6	137	278. 6	181	357. 8
−16	3. 2	28	82. 4	138	280. 4	182	359. 6
−15	5. 0	29	84. 2	139	282. 2	183	361. 4
−14	6. 8	30	86. 0	140	284. 0	184	363. 2
−13	8. 6	31	87. 8	141	285. 8	185	365. 0
−12	10. 4	32	89. 6	142	287. 6	186	366. 8
−11	12. 2	33	91. 4	143	289. 4	187	368. 6
−10	14. 0	34	93. 2	144	291. 2	188	370. 4
−9	15. 8	35	95. 0	145	293. 0	189	372. 2
−8	17. 6	36	96. 8	146	294. 8	190	374. 0
−7	19. 4	37	98. 6	147	296. 6	191	375. 8
−6	21. 2	38	100. 4	148	298. 4	192	377. 6
−5	23. 0	39	102. 2	149	300. 2	193	379. 4
−4	24. 8	40	104. 0	150	302. 0	194	381. 2
−3	26. 6	41	105. 8	151	303. 8	195	383. 0
−2	28. 4	42	107. 6	152	305. 6	196	384. 8
−1	30. 2	43	109. 4	153	307. 4	197	386. 6
0	32. 0	44	111. 2	154	309. 2	198	388. 4
+1	33. 8	45	113. 0	155	311. 0	199	390. 2
2	35. 6	46	114. 8	156	312. 8	200	392. 0
3	37. 4	47	116. 6	157	314. 6	201	393. 8
4	39. 2	48	118. 4	158	316. 4	202	395. 6
5	41. 0	49	120. 2	159	318. 2	203	397. 4
6	42. 8	50	122. 0	160	320. 0	204	399. 2
7	44. 6	51	123. 8	161	321. 8	205	401. 0
8	46. 4	52	125. 6	162	323. 6	260	500. 0
9	48. 2	53	127. 4	163	325. 4	288	550. 4
10	50. 0	54	129. 2	164	327. 2	320	608. 0
11	51. 8	55	131. 0	165	329. 0	370	698. 0
12	53. 6	56	132. 8	166	330. 8	430	806. 0
13	55. 4	57	134. 6	167	332. 6	480	896. 0
14	57. 2	58	136. 4	168	334. 4		

TABLE LIII.—*Weights of materials*

Material	Weight per cubic foot (pounds)
Aluminum:	
Cast	160
Wire	168
Asphaltum	69–94
Brass	510–542
Brick	110–130
Bronze	545–555
Coal:	
Anthracite	97
Bituminous	84
Charcoal	17–35
Concrete:	
Reinforced	150
Stone	140–150
Copper, cast	549–558
Crushed—	
Gravel	95–104
Granite	90
Limestone	94
Earth:	
Clay:	
Dry, compact	100
Damp, plastic	110
Common—	
Loose, dry	70
Moist, rammed	100
Loam	65–88
Mud, wet:	
Fluid	104–120
Pressed	110–130
Sand:	
Pure quartz, dry:	
Loose	87–106
Rammed	100–120
Natural, loose	80–110
Earth—Continued	
Sand—Continued	
Wet	118–128
Gravel, clay mixed:	
Compact, dry	100
Wet	115
Gravel:	
Loose	82–125
Rammed	90–145
Ice	56
Iron:	
Grey cast	439–445
Wrought	487–492
Lead	710
Lime	53–75
Masonry:	
Mortar rubble	155
Dry rubble	125
Rock:	
Granite	125–187
Gravel, clean	100
Shale	162
Soapstone	162–175
Trap	187–190
Salt	129–131
Snow:	
Fresh fallen	5–12
Wet compact	15–20
Steel	474–494
Tin	455
Water:	
Fresh	62. 4
Sea	64. 0
Zinc	438

TABLE LIV.—*U. S. standard sieve dimensions*

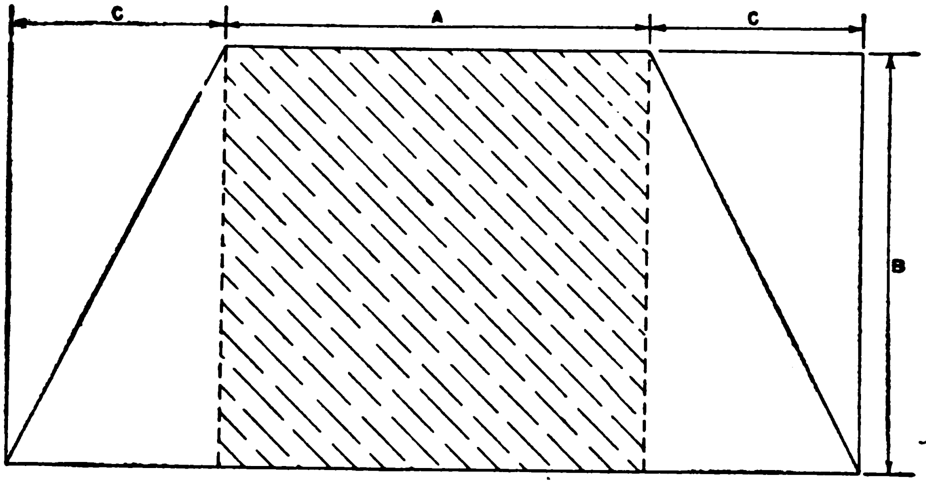
Bureau of Standards sieve number	Specified sieve opening		Specified wire diameter	
	Inches	Millimeters	Inches	Millimeters
4	0.187	4.76	0.050	1.27
5	.157	4.00	.044	1.12
6	.132	3.36	.040	1.02
7	.111	2.83	.036	.92
8	.0937	2.38	.0331	.84
10	.0787	2.00	.0299	.76
12	.0661	1.68	.0272	.69
14	.0555	1.41	.0240	.61
16	.0469	1.19	.0213	.54
18	.0394	1.00	.0189	.48
20	.0331	.84	.0165	.42
25	.0280	.71	.0146	.37
30	.0232	.59	.0130	.33
35	.0197	.50	.0114	.29
40	.0165	.42	.0098	.25
45	.0138	.35	.0087	.22
50	.0117	.297	.0074	.188
60	.0098	.250	.0064	.162
70	.0083	.210	.0055	.140
80	.0070	.177	.0047	.119
100	.0059	.149	.0040	.102
120	.0049	.125	.0034	.086
140	.0041	.105	.0029	.074
170	.0035	.088	.0025	.063
200	.0029	.074	.0021	.053
230	.0024	.062	.0018	.046
270	.0021	.053	.0016	.041
325	.0017	.044	.0014	.036

TABLE LV.—*Approximate round and square opening equivalents for testing sieves*

Square openings (inches)	Round openings (inches)
4	4¾
3¾	4½
3½	4¼
3⁵⁄₁₆	4
3⅛	3¾
3	3½
2¾	3¼
2½	3
2¼	2¾
2⅛	2½
2	2⅜
1⅞	2¼
1¾	2
1½	1¾
1¼	1½
1⅛	1⅜
1	1¼
⅞	1
¾	⅞
⅝	¾
½	⅝
⅜	½
⁵⁄₁₆	⅜
¼	⁵⁄₁₆
³⁄₁₆ (No. 4)	¼
⁵⁄₃₂ (No. 5)	³⁄₁₆
³⁄₃₂ (No. 8)	⅛

Adapted from Table 5, Simplified Practice Bulletin R 163-36 "Coarse Aggregates," published by the United States Department of Commerce. Numbered sieves are those of U. S. Standard Sieve Series.

TABLE LVI.—*How to calculate cubic content of windrows.*



To calculate cross-sectional area and volume in a windrow:

Steps: (1) Take measurements A, B, and C.
(2) A x B = area of rectangular center part.
(3) C x B = area of both triangular side parts.
(4) (A x B)+(C x B) = Total cross-sectional area of windrow.
(5) Volume in cu. ft. of a windrow is obtained by multiplying cross-sectional area in sq. ft. by length in ft.

Example: (1) By measurement A = 2 ft., B = 2 ft., C = 1 ft.
(2) A x B = 2 x 2 = 4 sq. ft.
(3) C x B = 1 x 2 = 2 sq. ft.
(4) (A x B)+(C x B) = 4+2 = 6 sq. ft. cross-sectional area.
(5) This windrow contains 6 cu. ft. of volume for each ft. of length. If the windrow is 1200 ft. long, the volume is 6 x 1200 = 7200 cu. ft.

TABLE LVII.—*Earth fill volumes*

FORMULAS

a. For computing volumes of earthwork:

$$V = \frac{(A_1 + A_2)}{2} \times \frac{L}{27}$$

Where

V= volume of cut or fill in cubic yards.
A_1= area of cross section at one end in square feet.
A_2= area of cross section at other end in square feet.
L= distance between end sections in feet.

b. For transportation of earth, gravel or crushed rock:

$$Q = \frac{60}{d + \frac{2h}{r}} \times C$$

Where

Q= cubic yards, place measure, moved per hour.
h= length of haul in feet.
C= cubic yards moved per load.
r= rate of vehicle in feet per minute (normally about 200 for animal drawn vehicles; 700 for trucks).
d= minutes during which vehicle is not in motion (loading, unloadi waiting).

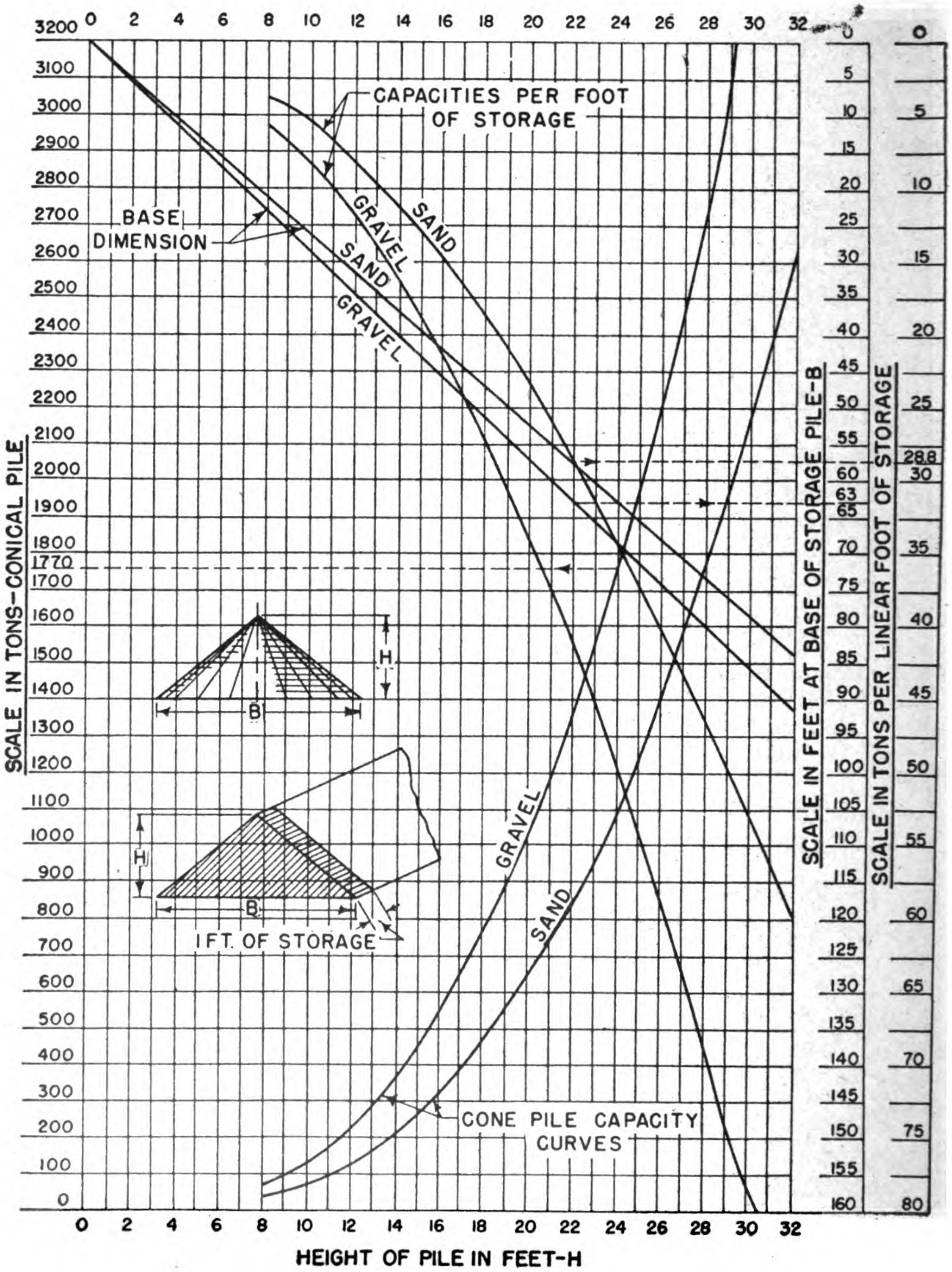
c. Volume of conical crater:

$$V = \frac{\pi D^2 d}{12}$$

Where

V= volume in cubic yards.
π= 3.1416 or $\frac{22}{7}$ approximately.
D= distance across crater in yards.
d= depth of crater in yards.

TABLE LVIII.—*Storage capacity curves.*



EXPLANATION

a. Storage capacity of a conical pile.—Enter the chart on the horizontal line at the bottom and mark off the height of the pile in feet. Then proceed upward vertically to the point where the proper curve intersects this vertical line. Proceed horizontally from this point of intersection to the column at the left and read capacity in tons. For example, a 24-foot-high conical pile of gravel will hold 1,770 tons. (See arrow and dotted line on chart.)

b. Storage capacity of triangular pile (fig. 204).—The two ends form one conical pile. The capacity of this can be determined as in *a* above. The intermediate pile can be figured from the "capacities per foot of storage" curves on the chart. Mark off the height of the pile in feet along the horizontal line at the top of the chart. Then, proceed vertically downward from this point to intersect a downward curving line (group of 2 curves marked "capacities per foot of storage") for the proper material. From this point of intersection, proceed horizontally to the last column at the right and read the number of tons per linear foot of storage. For example, a pile of sand 22 feet high will have 28.8 tons per foot of storage. (See arrow and dotted line on chart.) This answer, multiplied by the number of linear feet in the intermediate section of the pile, will be the total weight of the material in this section. If the weight of the material in the conical section is added to that for the intermediate section, the result will be the capacity of the entire pile.

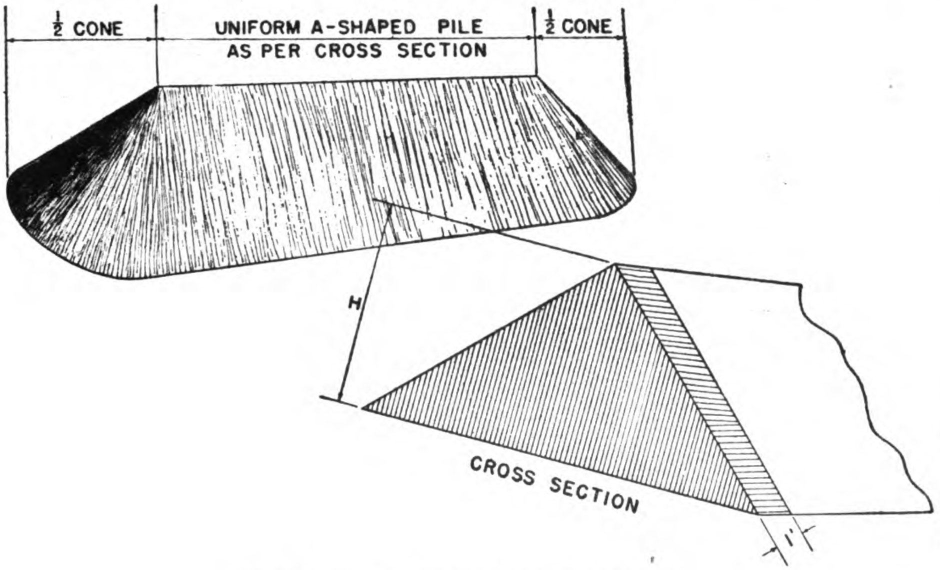


FIGURE 204.—Storage capacity curves.

c. Computing base dimension.—The third set of curves on the chart are the "base dimension" curves. By their use it is possible to find the width of the base of a pile if its height is known. To use them enter the chart from the point corresponding to the number of feet in the height of the pile. Then, move vertically upward on this line to intersect the proper "base dimension" line. Next, move horizontally from the point of intersection to the first column at the right and read the width in feet of the base of the pile. For example, a pile of gravel 22 feet high will extend over a base area 63 feet wide. If it is a conical pile, 63 feet is the diameter of the circular area at its base. (See arrow and dotted line on chart.)

TABLE LIX.—*Approximate quantity of surface water carried by average aggregates*

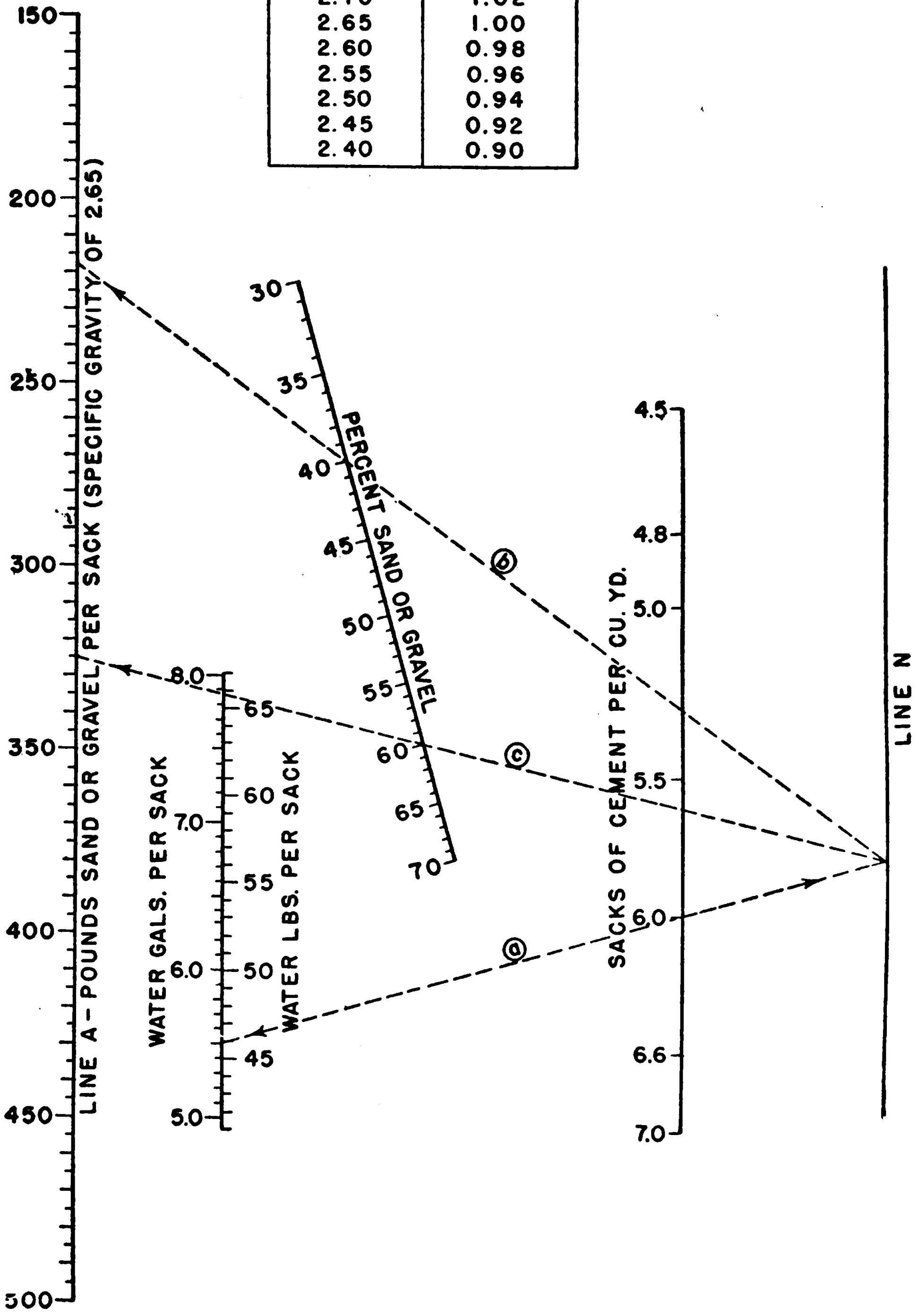
Aggregate	Gallons per cubic foot
Very wet sand	¾ to 1.
Moderately wet sand	About ½.
Moist sand	About ¼.
Moist gravel or crushed rock	Do.

TABLE LX.—*Quantity of materials in concrete mixes*

Mix by volume job damp materials	Materials per cubic yard of concrete			1 bag batch (cu. ft.)
	Cement (sacks)	Sand (cu. ft.)	Stone (cu. ft.)	
1:1¼:2	9. 6	12. 0	19. 1	2. 82
1:1½:3	7. 6	11. 4	22. 8	3. 55
1:2:3	7. 1	14. 2	21. 3	3. 82
1:2:3.5	6. 5	13. 0	22. 7	4. 16
1:2:4	6. 0	12. 0	24. 0	4. 47
1:2.2:3	6. 8	15. 0	20. 4	3. 97
1:2.2:3.5	6. 3	13. 9	22. 2	4. 26
1:2.5:3	6. 5	16. 1	19. 4	4. 18
1:2.5:3.5	6. 0	15. 0	21. 0	4. 49
1:2.5:4	5. 6	14. 0	22. 4	4. 83
1:2.5:5	5. 0	12. 5	25. 0	5. 43
1:3:5	4. 7	14. 1	23. 5	5. 76
1:3:6	4. 2	12. 6	25. 2	6. 38
1:3¼:4	5. 2	16. 2	20. 8	5. 21
1:3¼:5	4. 6	14. 5	23. 2	5. 82
1:3¾:5	4. 3	16. 0	21. 4	6. 32
1:3¾:6	3. 9	14. 7	23. 5	6. 89
1:1½	15. 5	23. 3		1. 77
1:2	12. 8	25. 6		2. 13

TABLE LXI.—*Concrete mixes*

WEIGHT CORRECTION FACTORS	
SP. GRAV.	FACTOR
2.90	1.09
2.85	1.07
2.80	1.06
2.75	1.04
2.70	1.02
2.65	1.00
2.60	0.98
2.55	0.96
2.50	0.94
2.45	0.92
2.40	0.90



EXPLANATION

The chart is used for rapidly proportioning and checking concrete mixes. For example, a mix is to be prepared using six sacks of cement per cubic yard of concrete and having a water-cement ratio of 5.5 gallons per sack. Fine aggregate is sand with a specific gravity of 2.60. Coarse aggregate is gravel with a specific gravity of 2.70. A mix using 40 percent sand and 60 percent gravel is selected for trial. Weight proportions for this trial mix are found as follows:

a. Place a straightedge at 6 sacks per cubic yard and at 5.5 gallons per sack and project a line to intersect line N.

b. Place a straightedge at the intersection on line N and at 40 percent for sand and project to intersect line A, in this case 218 pounds sand.

c. Place a straightedge at the same intersection on line N and at 60 percent for gravel and project to intersect line A, in this case 325 pounds gravel.

d. The weights of sand and gravel are corrected for specific gravity by multiplying by the "weight correction factor" for the respective specific gravities as follows:

Sand=218×0.98=214 pounds
Gravel=325×1.02=332 pounds

e. The proportions for the trial mix per sack of cement are—

5.5 gallons water: 1 sack (94 pounds) cement: 214 pounds sand; 332 pounds gravel.

f. The proportions in a batch using four sacks of cement, for example, are obtained by multiplying by 4:

22 gallons water: 4 sacks cement: 856 pounds sand; 1,328 pounds gravel.

A few trial batches are prepared using these proportions. Subsequent adjustments are made as needed until a satisfactory mix is obtained by changing the percentages of sand and gravel and recomputing their weights as above.

TABLE LXII.—*Sizes of wire nails*

Size	Length (inches)	Number per pound	Size	Length (inches)	Number per pound
2d	1	900	20d	4	29
3d	1¼	615	30d	4½	23
4d	1½	322	40d	5	17
5d	1¾	250	50d	5½	13½
6d	2	200	60d	6	10½
7d	2¼	154	70d	7	7
8d	2½	106	80d	8	6
9d	2¾	85	90d	9	5
10d	3	74	100d	10	4
12d	3¼	57	120d	12	3
16d	3½	46			

APPENDIX VI

BIBLIOGRAPHY

NOTE.—These publications are recommended for use by aviation engineers.

1. Military.—*a. Field Manuals.*

Reference Data, Administration	FM 1-55
Troops and Operations	FM 5-5
Communications, Construction, and Utilities	FM 5-10
Field Fortifications	FM 5-15
Camouflage	FM 5-20
Explosives and Demolitions	FM 5-25
Engineer Antimechanized Measures	FM 5-30
Reference Data	FM 5-35
Military Training	FM 21-5
Elementary Map and Aerial Photograph Reading	FM 21-25
Advanced Map and Aerial Photograph Reading	FM 21-26
Defense Against Chemical Attack	FM 21-40
Identification of U. S. Government Aircraft	FM 30-30
Field Service Regulations—Larger Units	FM 100-15

b. Technical Manuals.

Electrical Fundamentals	TM 1-455
Topographic Drafting	TM 5-230
Surveying	TM 5-235
Aerial Photography	TM 5-240
Protective Concealment for Airdromes and Other Fixed Installations	TM 5-266
Materials for Protective Concealment	TM 5-269
Construction in the Theater of Operations	TM 5-280, TM 5-281
Water Supply and Water Purification	TM 5-295
Military Protective Construction	TM 5-310

c. Maintenance manuals and parts catalogs.—Manuals covering operation, repair, and lubrication of each item of engineer equipment and containing a parts list are furnished by equipment manufacturers. If copies of these manuals do not accompany equipment, they may be obtained from Spare Parts Branch, Engineer Supply Section, Columbus Quartermaster Depot, Columbus, Ohio, by requisition giving basis of equipment issue.

2. Technical.

a. Engineering Manual, Corps of Engineers.

b. Airport Design Information, Civil Aeronautics Administration.

c. Airport Construction Specifications, Civil Aeronautics Administration.

d. Specifications for Construction of Roads and Bridges, FP-41, Public Roads Administration.

e. Standard Specifications for Highway Materials and Methods of Sampling and Testing, American Association of State Highway Officials, National Press Building, Washington, D. C.

3. Textbooks (available by purchase).

a. Engineering Properties of Soil, by C. A. Hogentogler. McGraw-Hill, New York.

b. Highway Design and Construction, by Bruce. International Textbook Co., Scranton, Pa.

c. Highway Engineer's Handbook, by Harger and Bonney. McGraw-Hill, New York.

d. Highway Materials, by Bauer. McGraw-Hill, New York.

e. Plain Concrete, by Bauer. McGraw-Hill, New York.

4. Trade association publications (available by request).

a. Cement construction.

(1) *Design and Control of Concrete Mixtures.* Portland Cement Association, Chicago.

(2) *Soil-Cement Roads* (Construction Handbook) and *Soil-Cement Mixtures* (Laboratory Handbook). Portland Cement Association, Chicago.

(3) *Manuals on Design, Construction and Inspection of Concrete Pavements for Roads and Airports.*

b. Asphalt construction.

(1) *Asphalt Pocket Reference for Highway Engineers.* The Asphalt Institute, 801 Second Ave., New York, or 100 Bush St., San Francisco.

(2) *Asphaltic Pavements for Airports.* The Asphalt Institute, 100 Bush St., San Francisco.

c. Drainage.

(1) *Airport drainage.* Armco Drainage Products Association, Middletown, Ohio.

(2) *Bulletins* on drainage may also be obtained from American Concrete Pipe Association, 33 W. Grand Ave., Chicago.

5. Other (available by request).

a. Equipment.—Bulletins may be obtained directly from equipment manufacturers.

b. Tar construction.—Bulletins may be obtained directly from manufacturers of tar products, such as *The Barrett Road Book,* The Barrett Co., 40 Rector St., New York, and Tarmac Handbook, the Koppers' Co., Pittsburgh, Pa.

c. Construction methods and materials.—*Materials and Methods for Military Airport Construction.* Barber-Greene Co., Aurora, Ill.

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[A. G. 062.11 (11-16-42).]

BY ORDER OF THE SECRETARY OF WAR:

G. C. MARSHALL,
Chief of Staff.

OFFICIAL:
J. A. ULIO,
Major General,
The Adjutant General.

DISTRIBUTION:
X.
(For explanation of symbol see FM 21-6.)

U. S. GOVERNMENT PRINTING OFFICE: 1942

NON-CIRCULATING BOOK